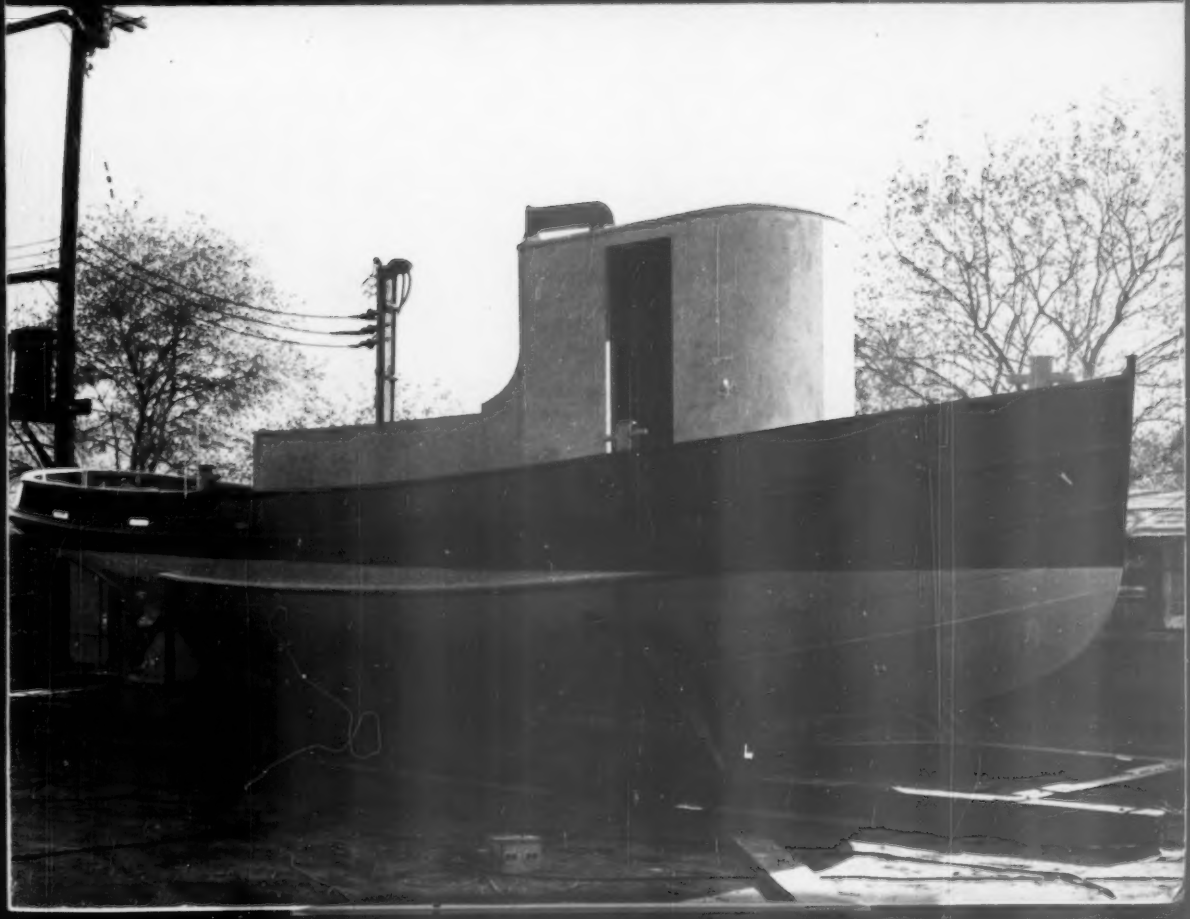
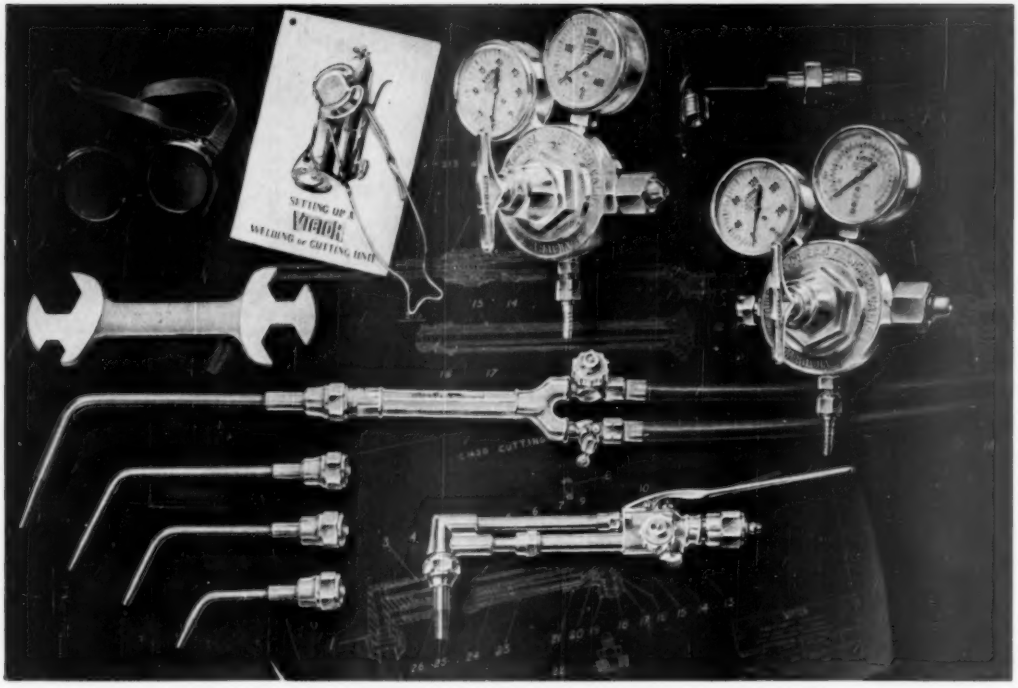
WELDING JOURNAL





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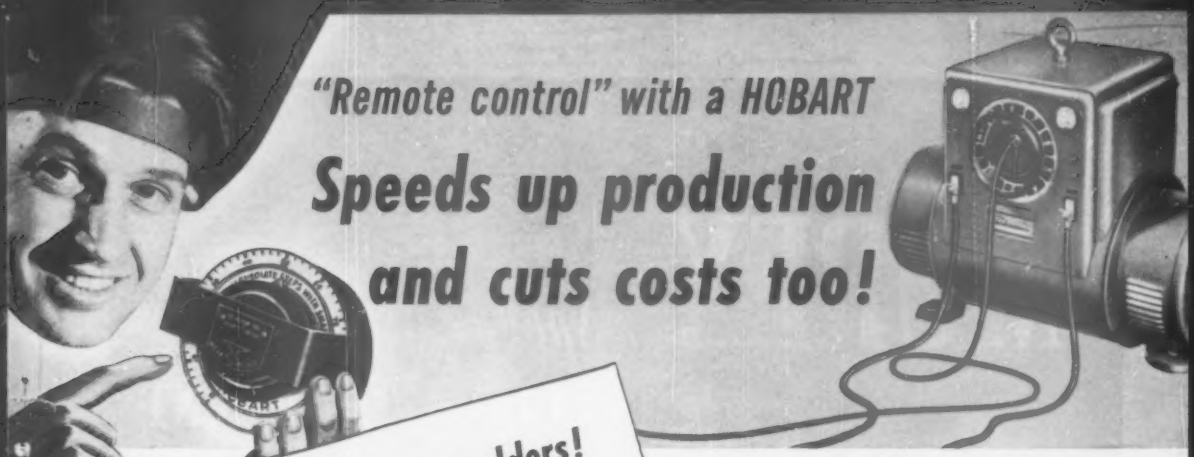

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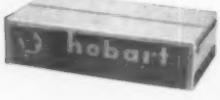

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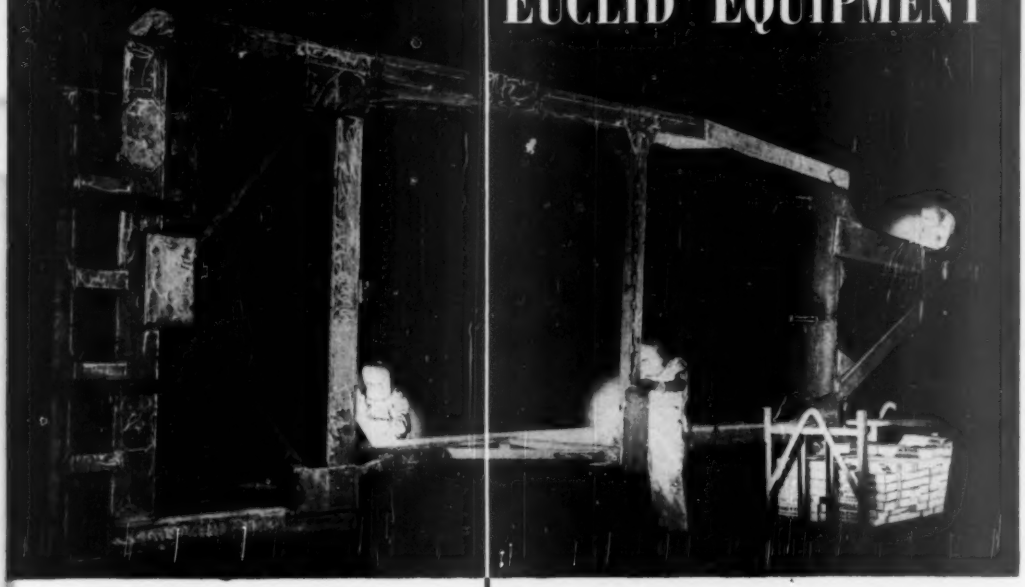

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cover: Tugboat built by the American Electric Welding Company, Inc., of Baltimore, has an all-welded hull fabricated of wrought iron plates.

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LINDE'S News of Metalworking

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Most important from the mill's standpoint was the fact that the upper brickwork was not damaged. Damage from other methods of removing the salamander could run as high as $300,000 worth of brickwork.

The OXWELD C-60 Blowpipe is specially designed for extra heavy cutting. And when powder-cutting is used refractory oxides are no problem.

What's News

▶ Of special interest to quarry men is LINDE'S Jet-Piercing blowpipe which can pierce holes to a depth of 5 ft. in hard and abrasive rocks and ores. This economical, speedy method makes blast holes in granite at a rate of 22 to 25 ft. per hour.

▶ One pipe manufacturer has produced a record seventy miles of 24-in. pipe (12,990 tons) in one month with the help of UNIONMELT welding.

▶ By using oxy-acetylene flame-cleaning, a foundry has cut the time required to clean slag from the center of their 20-in. castings from about 6 hours to 5 minutes.

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WHEN WELDS MUST BE MACHINABLE

1. The 45-pound iron pump casing shown above was defective as cast. Part of the intake flange was missing. A bad blowhole had all but destroyed an important boss.

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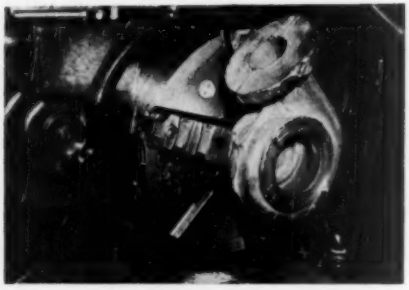
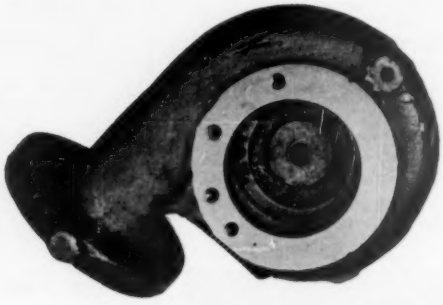
2. The bad casting was sent to the welding shop with orders to repair if possible. And . . . thanks to NI-ROD . . . it was possible!

Defective areas were chipped out with a cold chisel and filled with five weld layers, two beads per layer. Each bead was wire-brushed before laying down the next deposit. 5/32 in. NI-ROD was used.



3. The welded flange face was turned down at 185 ft. per min., using a carbide cutting tool with .117-in. feed. The flange bore was machined at the same speed, using a tool steel cutter and .012-in. feed.



4. After machining, bolt holes were drilled and tapped in the weld, fusion zone and cast metal. Although there was a thin area of hardness at the surface near the line of fusion, no difficulty was encountered during any of the finishing operations.

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The WELDING JOURNAL

volume 29 December, 1950 number 12

Hard Facing of Steam Valve Seats and Disks

An outline of general welding procedure, the fundamental differences in heating effects of low, medium and high velocity tips and evaluation devices employed at the U. S. Naval Engineering Experiment Station

by Oscar E. Swenson

Abstract

Hard facing of high-temperature, high-pressure steam valve seats and disks is a generally accepted practice. Engineering and catalog information do not, however, emphasize sufficiently the importance of selecting low-velocity welding tips for applying the hard overlays. One of the purposes of this paper, in presenting an outline of the general welding procedure and the fundamental differences in heating effects of low, medium and high velocity tips, is to stress the benefits of employing low velocity tips.

It is shown that different overlay compositions, such as chrome-nickel-boron, chrome-cobalt-nickel-molybdenum and cobalt-chrome-tungsten may be interchanged when flame ratios and deposition conditions are controlled.

A descriptive explanation of the methods for evaluating hard-facing alloys and testing devices designed at the U. S. Naval Engineering Experiment Station for determining hot hardness, hot impact values and steam tightness are included to interest both the engineer and the welder.

Terminology in the field for the degree of acetylene flame varies widely. Consideration is suggested to designating a descriptive mathematical ratio of length of acetylene feather to length of inner cone for a qualitative measure of the amount of acetylene flame.

INTRODUCTION

NATURE renews herself by growth; man-made machines wear out. Since the beginning of welding, one of its many uses has been the reclamation of worn parts; and for this purpose, special hard-facing materials and techniques have gradually been developed.

Oscar E. Swenson is Welding Engineer, U. S. Naval Engineering Experiment Station, Annapolis, Md.

Presented at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

This paper presents the author's personal opinions and assertions, which do not necessarily reflect the official attitude of the Navy Department.

Hard facing by braze welding provides the engineer with a convenient method for obtaining a hard wear-resistant surface on metal parts. Special alloys in the form of welding rods and portable oxyacetylene welding equipment make the process readily applicable whether in the shop, aboard ship or on the beachhead. The useful application of hard-facing materials depends upon the selection of appropriate welding rods and equipment, the skill of the welder, and the engineering knowledge that permits good judgment in utilizing the materials.

Hard facing forms a protective layer which resists abrasion, corrosion, impact, seizure, heat or any combination of these wear factors. The primary function of hard facing is to prolong the life and increase the operating efficiency of the part involved. New, as well as worn parts, may obtain these benefits by the application of a thin layer of hard alloy to the position where it is most needed. In fact, hard facing finds its greatest over-all economy when applied to new parts.

PURPOSE OF TRIMMING VALVES

The welding operation known as hard facing has proved to be a practical and economical procedure for trimming valves.

The Navy requires that valve seats and disks for high-temperature, high-pressure steam service be furnished with hard facings. Hard-faced valves reduce power losses to a minimum and are free from scoring and undercutting even under the severe conditions of drip or throttle service. Repeated heating and cooling does not warp or distort the properly applied wear-resistant overlays. In addition, the low coefficient of friction of the hard-facing alloys is especially valuable in valves where the disk travels in a rotating or wiping motion over the face of the seat.

GENERAL WELDING TECHNIQUE

The deposition of hard-facing alloys requires a braze-welding technique rather than a fusion welding technique. The surface to be overlaid must be clean and prepared by grinding or machining to remove all oxide and scale. The following is presented as a general guide for applying hard-facing alloys.

Welding Torch and Tip Sizes

Any approved type of oxyacetylene welding torch with low velocity tips may be used for the deposition of hard-facing alloys. It is important that the high velocity tips be avoided as the force of the flame jet may cause localized overheating of the base metal with resultant dilution of the hard-facing deposit and erratic hardness results. A, B and C in Fig. 1 illustrate the differences between low, medium, and high velocity tips. Note the square shoulders in the low velocity tip, the slanting shoulders in the medium velocity tip and the straight-lined swaged taper for the high velocity tip. The inner cone of the low velocity tip has a pronounced bulbous shape which spreads the heat onto the base metal. As illustrated, the inner cone lengthens and the bulb becomes smaller as the velocity of the gas increases. Tip sizes should be: 0.0465 bore (No. 56 drill) for material not over $^3/_{16}$ in. thick; 0.0670 bore (No. 51 drill) for material $^1/_4$ to $^7/_{16}$ in. thick; 0.0760 bore (No. 48 drill) for material $^1/_2$ in. thick and over.

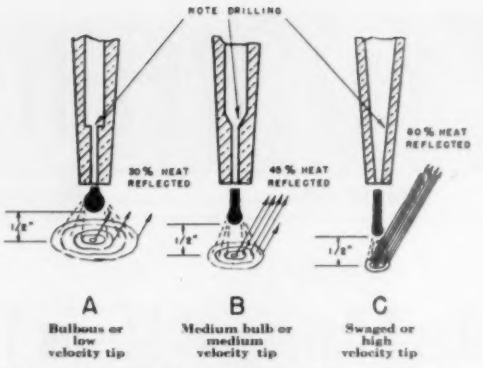

Fig. 1 Illustrating heating effects of low, medium and high velocity tips

As velocity of gas increases due to the drilling inside of tip, the inner cone lengthens and the flame bulb becomes smaller

(Modification of a copyrighted illustration, courtesy of the Walworth Company)

Flame Adjustment

The flame for hard-facing alloys must contain an excess of acetylene. One exception to this rule is the application of Alloy "C" on objects of small mass requiring only local preheat and a neutral flame. The desired flame adjustment for each alloy is shown in Table 1 as a ratio between the length of acetylene feather and the length of the inner cone, both being measured from the end of the torch tip. Illustrations of a neutral flame, 2:1 and 4:1 ratio flames are shown in Figs. 2, 3 and 4, respectively. Acetylene and oxygen 2-stage pressure regulators are preferred, and the settings should be 4–5 psi. for a No. 3 tip, 5–7 for a No. 5 tip and 6–8 for a No. 6 tip.

Acetylene gas requires $2^1/_2$ times its own volume of oxygen for complete combustion. Approximately equal volumes of the two gases are fed through the torch, and the remaining $1^1/_2$ volumes of oxygen are obtained from the air.

When the acetylene gas is burning without the oxygen gas turned on, it has a brilliant white flame caused by white-hot carbon particles, some of which escape unburnt and can be seen floating in the air. As the oxygen

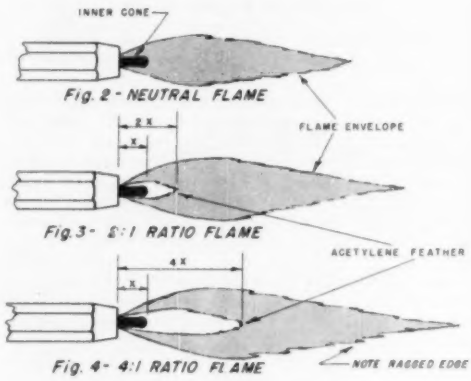

Table 1

NON-FERROUS HARD-FACING ALLOYS			
HARD-FACING ALLOY	*APPROXIMATE COMPOSITION*	*FLAME ADJUSTMENT RATIO**	*DEPOSITION CONDITIONS*
A	Co. 55% Cr 33% W 6%	3 : 1 TO 5 : 1	1-HIGHLY REDUCING FLAME IS ESSENTIAL IN MOST APPLICATIONS. 2-DEPOSITION IS MOST SATISFACTORY WHEN MADE WITH A MINIMUM OF REMELTING.
B	Cr 13% Ni 76% B 3%	2 : 1	1-SLIGHTLY REDUCING FLAME IS PREFERRED. 2-DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.
C	Cr 17% Ni 70% B 4%	1 : 1 TO 3 : 1	1-MODERATELY REDUCING FLAME IS PREFERRED IN MOST APPLICATIONS. FOR OVERLAYING SMALL OBJECTS A NEUTRAL FLAME IS RECOMMENDED. 2-DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.
D	Cr 25% Co. 21% Ni 13% Mo. 8%	3 : 1	1-MODERATELY REDUCING FLAME IS PREFERRED. 2-DEPOSIT CAN BE REMELTED TO IMPROVE CONTOUR.

*LENGTH OF ACETYLENE FEATHER TO LENGTH OF INNER CONE.

is turned on and adjusted to give a neutral flame the size of the white flare decreases until it does not extend beyond the small white cone. When the acetylene supply is increased the white flare again appears, indicating that free carbon particles are present. When a flame with this acetylene feather is used for hard facing, the carbon particles tend to carburize the surface of the base metal and also to reduce any oxides of metal. The excess acetylene flame is thus both carburizing and reducing.

Terminology in the field for the degree of acetylene flame varies widely. Consideration is suggested to designating a descriptive mathematical ratio of length of acetylene feather to length of inner cone for a qualitative measure of the amount of acetylene flame.

Size of Welding Rod

The $^{3}/_{16}$-in. diameter welding rod is handled most conveniently, but when the width of the surface to be overlaid is less than $^{1}/_{4}$ in. or when the base metal thickness is less than $^{3}/_{16}$ in., a $^{1}/_{8}$-in. diameter rod should be used. If the smaller rod is not available, it may be produced by drawing out the larger rod as the soft flame from a tip with a 0.0465-in. bore, adjusted as for hard surfacing, is directed on the end of the rod to bring it to a plastic condition. Figure 5 illustrates the drawing out of a $^{3}/_{8}$-in. rod onto a heavy chill table. The skilled operator does not require a mold, but the beginner may find a grooved plate of carbon, graphite, iron or steel to be helpful. A length of angle iron could be used as a mold. The drawn out rod can be redrawn to progressively smaller diameters, if desired.

Use of Flux

Flux is not required, under normal conditions, for deposition of a dense overlay. The general rule is to avoid the use of flux.

Support of Thin Sections

When depositing on seats of thin sections it is often necessary, in addition to using a small welding tip, to back up the underside of the seat with wet asbestos fibre cement or carbon paste to absorb the excess heat. This method permits the heating of the base metal to the temperature required to form a union with the deposited alloy, yet prevents the melting of the base metal which would cause dilution of the alloy. Melting of the base metal may be prevented by slightly rounding any sharp corners in preparation of the surface to be overlaid. An excessive melting of the base metal forms an alloy with the overlay to give a deposit of unpredictable behavior.

For hard facing such light work as the point of a high-pressure needle valve, an Aircraftsman's small torch can be better regulated than the standard size unit, even though the latter is used with a No. 0 or No. 1 tip. The hard-facing rod may be redrawn as often as is necessary to reduce its mass to match that of the light work.

Direction of Welding

The proper direction for progression of welding is obtained with the forehand method of deposition. The relative position of work, rod and flame for starting deposition is shown on Fig. 6, and the finishing position is shown on Figure 7. As most welders are right-handed, the following description for applying hard-facing alloys may be considered standard.

The torch is held in the welder's right hand, the welding rod in his left. During preheating, the flame is directed almost normal to the work surface at a distance gaged by the free length of the acetylene feather.

During deposition, the torch is tilted so that the flame is pointed in the direction of progression and held

Fig. 5 Drawing out rod to smaller diameter

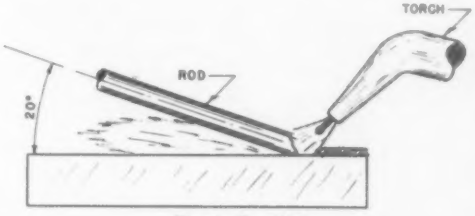

Fig. 6 Starting

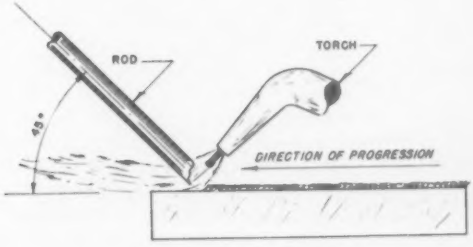

Fig. 7 Finishing

close enough to the work so that the inner cone of the flame is not more than 1/8 in. from the surface.

Pointing the flame to the left as the direction of welding progresses from right to left, permits the gas envelope to shield the metal as it melts from the rod and flows evenly on the work, while impurities are floated out.

The rod, carried in the welder's left hand, is held at about 20 to 45° above the horizontal (see Figs. 6 and 7), so that the welder's vision is not impaired and his hands are not exposed to the rising heat of the flame. The rate of melting off, the flowing on, the leveling and scavenging of the deposit are thus always in full view of the welder.

Preheating

It is advisable to preheat the entire surface of the work that is to be overlaid. The degree of preheating depends upon the mass of the work. Small objects are given only a local preheat while heavier pieces (5 lb. and over) must be preheated to not less than 650°F, preferably in a furnace. Preheating is mandatory to avoid localized dilution which results when employing high torch-fed heat, and to prevent the formation of porosity. A lower velocity rate of heat input from the oxyacetylene flame permits a larger portion of the base metal to absorb more of the total heat applied before fusion occurs. Careful preheating lowers thermal gradients and thus minimizes cracking tendencies. Contact pyrometers or temperature smear sticks may be used to determine when 650°F has been reached. Care must be exercised not to apply the smear on the clean surface prepared to receive the hard-facing alloy.

For smaller objects, the welder need only apply a light over-all preheat and then hold the flame on the spot where deposition is to start until sweating appears to be constant and begins to spread ahead of the flame. During this period of localized heating, the welding rod should also be preheated by being kept at the outer edge of the flame envelope. When the sweat of the preheated surface does not disappear the instant the torch is lifted slightly, the base metal is ready for overlaying.

Deposition

The welding rod is put into the flame slightly ahead of the inner cone and melted onto the work. As soon as the first large drop of hard-facing alloy is on the base metal, the welding rod is withdrawn from the center of the flame. If the base metal is sufficiently hot, the alloy flattens out and flows ahead of the flame, spreading on the work exactly like solder. If freshly deposited Alloy "A" does not spread out, it has to be heated with the torch until it does. The other alloys in Table 1, however, may be deposited rough and then remelted readily to obtain a smooth bead contour. Avoid puddling and penetration of the base metal as this dilutes the deposit and lowers its resistance to abrasive wear.

The flame must be kept on the deposit until all impurities have been floated off; these appear as white flecks swimming on top of the deposit. The deposit must look bright and smooth before additional metal is added to it. Once the base metal is of the correct temperature for spreading the deposit, progress of the work is rapid. It consists of alternately dropping the metal from the rod onto the end of the existing deposit, withdrawing the rod to the outer edge of the flame, and playing the flame on the last drop until the deposit is free of impurities. The required thickness of the overlay shall be deposited in a single layer whenever it is possible to do so. When, upon completion of a deposition, porous spots and/or low areas are discovered, such parts shall be remelted with a low velocity flame and the conditions corrected before the deposit cools. When completing a circular deposit such as on disks, it is advisable to finish the deposition with a "shrinkage tail," i.e., the final deposit is carried up over the starting end of the bead and finished off at either side of the start to provide an extra "tail" of hard-facing metal. Upon remelting the deposition, the "shrinkage tail" provides material at the point where shrinkage requires additional metal.

Postheating and Cooling

It is considered good technique to bring the disk or seat to an even heat immediately after deposition is completed and then to place it in lime for slow cooling. One method is to back the torch off gradually from the work instead of removing the torch abruptly from the union between the first and last laid metal, so that possible cracking at the termination of the depositing is prevented. After completing the deposition, the flame is played on the disk or seat, passing around the work two or three times.

Precautions on Interchangeability

All of the alloys in Table 1 are interchangeable and satisfactory results may be obtained by observing the above instructions. A special precaution must be observed, however, when Alloy A is used to overlay Alloys B or C. As the melting point of Alloy A is higher than for either Alloy B or C, it is unavoidable to remelt a small volume of the latter metals when a repair is effected with Alloy A. To avoid development of porosity in the repair area, the deposition of Alloy A must be performed with a highly reducing flame adjustment with the ratio of the acetylene feather to the inner cone at 5:1. It is mandatory to remelt only the unavoidable minimum volume of the original overlay. Best results are obtained when the deposited Alloy A does not require remelting. Should remelting Alloy A be necessary, it may be done using care that the jet of the flame does not cause a depression in the heated overlay. The soft flame of the low velocity tip will aid in observing this precaution.

NONFERROUS HARD-FACING ALLOYS

The nonferrous hard-facing alloys have been found most suitable for trimming high-temperature steam valves. Some of these alloys are shown in Table 1, with their approximate composition, flame ratios, and deposition conditions for best results. Properties which make the nonferrous alloys desirable for overlaying steam valve seats and disks are (1) they maintain strength and hardness at elevated temperatures, (2) they resist abrasion and corrosion, (3) they have low coefficients of friction and (4) they have good welding characteristics.

DETERMINING SUITABILITY OF ALLOYS

To determine the suitability of hard-facing alloys for use in the Naval service, they are first given a screening test consisting of edge welds on $^3/_4$- x $^3/_4$- x 6-in. medium steel keystock and on $4^1/_2$-in. diameter disks cut from $^3/_8$-in. thick steels of carbon molybdenum, 25–20 stainless, and $^3/_8$-in. thick Monel metal. The welds are made in one-pass approximately $^1/_8$ in. thick and subsequently ground to a thickness of about $^3/_{32}$ inch.

During deposition, which is accomplished with the forehand technique, the flow characteristics, ease of deposition and bead contours are observed. Remelting characteristics of the alloys are noted when it is necessary to remove surface defects or to improve smoothness of the deposit. The ground deposits are examined for porosity, checks or blemishes of any type. Uniformity of hardness is determined for the ground deposit on the keystock. A minimum hardness of Rockwell C-40 is expected for the as-deposited alloys.

The ground disk specimens are subjected to thermal shock by placing them in a furnace, the temperature of which is maintained at 1050°F. Specimens are held in the furnace for 30 min. and then cooled in air to room temperature. This cycle is repeated 25 times with an examination of the overlay after each cycle for cracks, employing the Oil-Powder Flaw Detection Method.

Hard-facing alloys found acceptable to the above screening tests are subjected to hot hardness and hot impact tests. Specimens for hot hardness are deposited in single layers on $^3/_4$- x $1^1/_2$- x $1^1/_2$-in. blocks of 4–6 Cr, $^1/_2$ Mo steel. One specimen is tested at room temperature, and one at 1100°F. Typical Brinell hardness data, in Table 2, for overlays ground to $^1/_8$ and $^1/_{16}$ in. thickness includes hardness data on the base metal as affected by the heat of welding.

Simulated valve seat and disk assemblies, as shown under the 20-lb. hammer in Fig. 10, have overlays ground to $^1/_{16}$ or $^3/_{32}$ in. thickness for hot impact testing. Evaluating methods are given under the following description of the testing devices.

Table 2

Overlay Thickness	Brinell hardness — Room temperature Range	Room temperature Average	1100° F Range	1100° F Average
$^1/_8$"	367–391	378	279–299	286
$^1/_{16}$"	361–396	381	261–325	284
Base Metal	380–383	382	221–255	240

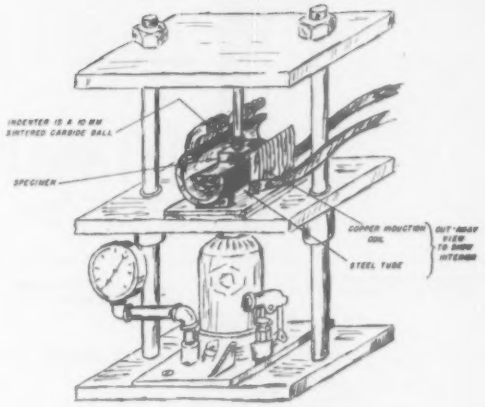

Fig. 8 Hot hardness tester

Testing Devices

Testing devices designed at the Engineering Experiment Station for determining hot hardness, hot impact values and steam tightness are shown in detail in Figs. 8, 10 and 11, respectively. A photograph of the hot impact machine is shown in Fig. 9.

The hot hardness machine is operated at temperatures up to 1100° F. The standard 3000-kg. load is applied to obtain the impression with a sintered carbide 10 mm. ball. The diameter of the impression is read in

Fig. 9 Hot impact machine

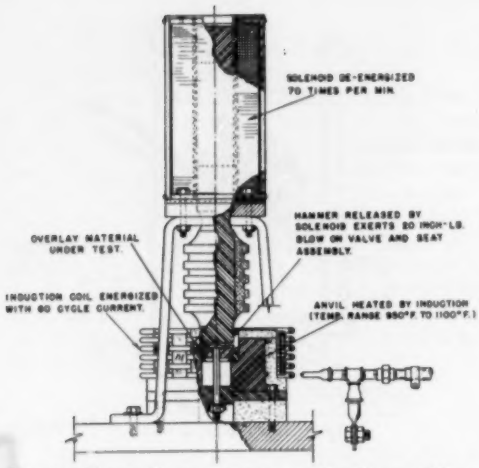
SOLENOID DE-ENERGIZED 70 TIMES PER MIN.
HAMMER RELEASED BY SOLENOID EXERTS 20 INCH-LB. BLOW ON VALVE AND SEAT ASSEMBLY.
OVERLAY MATERIAL UNDER TEST.
INDUCTION COIL ENERGIZED WITH 60 CYCLE CURRENT.
ANVIL HEATED BY INDUCTION (TEMP. RANGE 950°F. TO 1100°F.)

Fig. 10 Elevated temperature impact testing machine

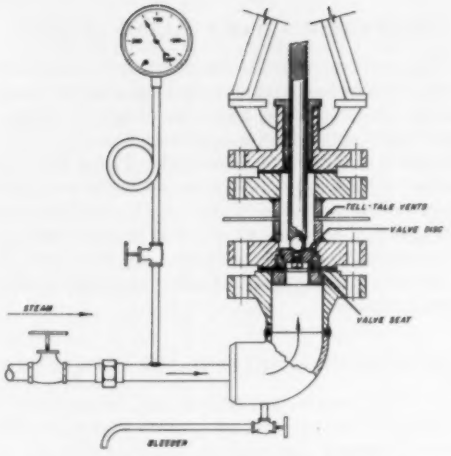

Fig. 11 Device for testing steam tightness

the usual manner with the Brinell microscope and converted to the Brinell hardness number.

The hot impact testing machine may be operated at various temperatures. The detail information on the sketch is self-explanatory. It has been determined that a satisfactory valve seat and disk overlay will withstand 500,000 impacts of the 20 in.-lb. hammer at the rate of 70 blows per minute without showing flaws when given the critical examination of the Oil-Powder Method.

The steam tightness tester is employed before and after subjecting the valve seat and disk assembly to hot impact. Any leakage of the saturated steam past the seat and disk would be seen at the telltale vents. This test aids in determining wear or defects in the overlay.

Actual service tests of hard-facing alloys can be performed at the Engineering Experiment Station not only in various steam lines, but also as exhaust valve overlays in various Diesel engines at the Station's Internal Combustion Engine Laboratory.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Bela Ronay, Superintendent, and J. H. Siegel, Welding Branch Head, Welding and Electrical Laboratory, U. S. Naval Engineering Experiment Station, for their helpful suggestions and constructive reviews of this paper; to J. W. Hopkins, Jr., Draftsman, for preparation of the sketches; and to other staff members of the Welding and Electrical Laboratory—particularly to F. X. Henderson, Welding Engineer, whose practical knowledge of hard facing was especially helpful.

WELDING METALLURGY

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Tracing Devices in Shape Flame Cutting

Principles of operation of the electronically guided template tracing devices, their preparation and application

by Raymond O. Fish

THE use of electronically guided devices for tracing templates in shape flame cutting is a comparatively recent innovation. The basic principles involved in its construction have been well known for several years but it has only recently been introduced as a production tool of inestimable value to shops doing a large volume of both repetitive and nonrepetitive flame cutting.

Shape flame cutting, by which we define as shapes having nonregular sides of no definite geometric pattern, was of course first realized with a manually guided hand torch. Simple tractors to carry the hand torch made it possible to flame cut geometric shapes and circles with a fair degree of accuracy, but these tractor type machines could follow only irregular outlines by having the shape laid out on a piece of plate and a repetitive job was slow and expensive. Enterprising engineers developed several arrangements for irregular cutting, among them a one to one ratio pantagraph, and also a floating arm mounted on a free rolling carriage on a track. These basic arrangements enabled a shop to make a full-sized template and with a torch and tracing wheel mounted on the same arm, repetitive flame cutting of shapes was a production reality. Motor-driven tracing wheels to follow patterns laid out on paper were introduced but the resulting shape was no better than the skill and dexterity of the operator since this was nothing more than a mechanized version of the manually guided hand torch. Several methods of mechanically guiding the tracing wheels were developed; one is the magnetic tracer which is a small magnetized revolving wheel which adheres by magnetism to the steel edge of a metal template. Other devices rely on a cleverly arranged set of mechanized fingers which follow a piece of aluminum or other soft metal bent in the shape of the piece desired.

For many years, these basic methods or variations from them represented the acme of shape flame cutting and have been effective in bringing welded fabrication to the fore as one of the nation's basic production methods.

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Presented at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

There have, in addition, been several attempts in the past at template simplification using electronic devices but they have not materialized in a readily available reliable production tool.

Refinements of equipment, remotely controlled lighting of torches, remotely controlled torch elevation, automatic spacing of torches from plate surfaces, torches to cut extremely heavy sections, elimination in variation in sides of flame-cut surfaces to avoid non-square edges; all of these and more improvements have been made to improve shape flame cutting but the device for following the template still had not been developed that would allow for precise, permanent, and simply prepared low-cost templates.

Intricate shapes of low volume production often required a template that was worth several times the value of the piece itself and many times it has been more profitable to lay out the desired shape full size and then shape cut it on a metal cutting band saw even though the cutting time was several times that required for flame cutting because of the excessive cost of the template itself.

Being constantly on the alert for methods to improve the flame cutting in our shops, we were interested several years ago with the announcement of an electronically guided tracing device which used the simplest of templates. After considerable investigation into its possibilities we secured several units and placed them in operation.

Before entering the discussion of its application, I should like to briefly review the actual mechanics of the device. I quote from the operating manual furnished by the manufacturers of the device, viz., the General Electric Co. and the Air Reduction Co.

MECHANICS OF OPERATIONS

Light is emitted from an exciter lamp and passes through an optical system, see Fig. 1. The optical system comprises a condenser lens, light aperture, an optical tube and an optical cell which contains focusing lenses and an optical prism. The light emerges from the optical system in the form of a small spot which is directed onto the template.

Photo tubes in the scanning head pick up the light reflected from this spot and produce an electrical signal.

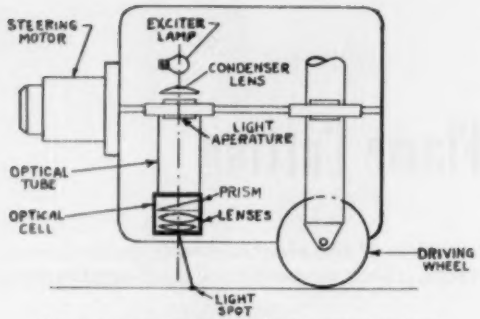

Fig. 1 The optical system in the scanning head

This signal controls the steering motor. The electronic circuit is so designed that the direction of the steering motor is determined by the intensity of the light reflected from the template surface. When the light is reflected from an entirely white surface (high intensity light), the motor rotates in one direction (say clockwise); when the light is reflected from an entirely black surface (low intensity light), the motor rotates in the opposite direction (say counterclockwise). When the light spot is centered half on a white area and half on a black area, the intensity of the reflected light is such that the control system is balanced and the steering motor is idle.

The optical system and the driving wheel housing are connected to the steering motor armature shaft through worm gear drives. Rotation of the steering motor armature thus causes the optical system and the driving wheel housing to rotate a like amount and in the same direction.

The optical prism deflects the light spot from the center line of the optical cell; thus, the light spot rotates about the center line of the optical cell when the cell itself rotates.

The deflected light spot is preset in a fixed leading position relative to the driving wheel in the direction of driving wheel travel. This lead is maintained at all times in this relationship, as both the optical system and the driving wheel housing rotate in unison.

This is the system by which the scanning head follows the outline of a drawing or silhouette of any desired shape. The head in turn directs the cutting torches when the head is mounted on the torch bar of a cutting machine.

Assume for instance, that the head is following a straight line portion of a drawing or silhouette, half of the light spot falling on the black line or pattern and half on the white background. The head is approaching a curve on the pattern. As long as the light spot is following a straight line portion of the pattern in this manner, there is no rotation of the steering motor—the steering motor is idle; the optical system and driving wheel do not change direction. When the light spot reaches a curve in the pattern, it starts to leave the black pattern and go into the entirely white background. This upsets the balance in the control system.

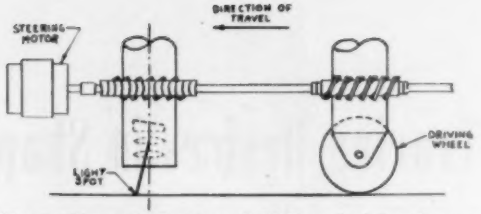

Fig. 2 The optical unit and driving wheel housing are turned simultaneously by the steering motor

The intensity of the reflected light is increased because it is now being reflected from a predominantly white surface. This sets the steering motor rotating in the direction necessary to bring the light spot toward the pattern on line to a position where the light is again half on the pattern and half on the background.

This action is continuous and keeps the light spot following the edge of the line or pattern no matter what direction it may take. Since the driving wheel housing is geared directly to the same steering shaft as the optical unit, the driving wheel is turned in the same direction as the light spot (Fig. 2). In this manner, the scanning head is made to follow any desired contour.

TEMPLATE PREPARATION

Low-cost templates are a must in a cost conscious flame cutting department and with the electronic tracing device, considerable ingenuity can be exercised by those charged with template preparation.

As in most shops doing a large volume of flame cutting, it requires the full time of one or more men devoted solely to template preparation and working closely with shop supervision, inspection, process and design engineering.

The foremost problem involved in template preparation for the electronic device was the selection of a template material that was easily procured, inexpensive, durable and accurate under a variety of conditions.

Paper was tried and was proved unsatisfactory over a period of time. Most papers of a heavy enough quality for handling in the shop were very sensitive to humidity and tests were conducted which revealed that 2-ft. diameter circles drawn on paper would grow or shrink as much as $^{3}/_{32}$ in. to the foot depending upon the humidity. A template made on a humid day would be undersized if used on a very dry day or templates made on a dry day would be oversize if cut on a humid day. Paper being generally light colored would soil easily and dark finger smears around the edges would affect operation of the device. The ever-present danger of sparks flying around led to damaged paper templates. Papers treated with synthetic resins and fabrics made from glass cloth were tried and while generally found to retain accuracy, yet the danger of soiling or damage by fire ruled their use out. In connection with paper templates, it became evident that line drawings with $^{1}/_{8}$-in. width black lines did not fit into our production setup

since the cost of outlining the shape was usually greater than cutting out the silhouette for use on contrasting colors. By far the greater percentage of our work involves silhouettes with very few line type of templates being made.

Thin sheets of dark plastic were tried as a source of template material and while satisfactory in general, they were also expensive and could not be so readily joined when large templates were required.

The answer for a permanent template obviously led in one direction, and that was a metal template. We secured several sheets of thin sheet metal and had them triple dipped in black paint; the paint used was semi-gloss electrical insulating enamel although experience has proved that a nonglossy paint is preferred. Since the metal was thin (29 ga.) it was easily cut to shape with tin snips, the black paint made an excellent base for accurate layout work and above all it was inexpensive and durable.

Small chisels for intricate radii and sharp corners were developed from ground down files so that tin snips were required only for straight line or larger radius work. In order to cover any damage done to the painted edge, a small brush dipped in black drawing ink is used to touch up the edges and gives the dull black edge for best reflection qualities.

Templates made as described offer unlimited possibilities as to size flexibility in use. Sheets may be spot-welded together to arrive at oversize templates. They may also be pinned so that multiple templates may be combined to give a high degree of flexibility in use.

Templates prepared as described are placed on top of white paper. This may be tag ends of blue print rolls or scrap blue prints with the blue side down and covered by $^1/_8$-in.-thick transparent acrylic plastic sheets. Paper templates of the cut out type are used on jobs of a nonrepetitive nature when they will be used generally on the same day as prepared. These white paper templates are placed over black masonite to get the color contrast and are also covered by a plastic sheet.

APPLICATIONS

Leading in or starting the cut offers no problem with templates used with the electronic tracing device. On conventional templates it is often necessary to use elaborate gates for the cam follower to start, proceed to the cut proper and the gate either had to be closed or removed from the template and lead ins made by this method were a constant source of difficulty offering as they did opportunities for flame cut scars of a severe nature.

With the electronic device two methods are possible. One is a small strip of material the same color as the template which is placed alongside the template at the correct lead-in angle. The simplest and preferred method is the tangent lead in arrived at by merely setting the driving wheel at the desired tangent and manually allowing the electronic tracer to approach the template and when the light spot is just off center

Fig. 3 Manual tracing device on oxyacetylene flame-cutting machine

from the edge of the template to snap the automatic switch and the light spot takes over control of the tracing motion. This method is easily accomplished and gives smooth starts and stops to flame cut edges and has been of inestimable value in reducing annoying and costly flame-cut scars from otherwise smooth flame-cut edges.

Figure 3 shows a paper template in use with a manual tracing wheel. The resulting shape will only be as accurate as the ability of the operator to follow the line and after a few times around the template, the original line will be partially obliterated and practically useless for further accurate work. This coupled with the growth and shrinkage of the paper leaves considerable to be desired.

Figure 4 shows a metal template used with a magnetic tracing wheel. The small diameter wheel is held to

Fig. 4 Magnetized wheel following metal template on multitorch oxyacetylene flame-cutting machine

the contour edge of the template by magnetism and tracing devices of this type require a fairly large diameter wheel to obtain the necessary magnetism. The template itself may be made as shown from $^3/_8$-in. plate or also may be made from thin bars set edgewise on a laid out surface. This amount of contact is necessary for enough magnetism to hold the wheel to the tracing surface. Templates of this nature while extremely accurate are expensive to make since they require a shape-cutting saw or milling machine to arrive at the desired contour. The metal strip template requires accurate layout and shape forming of the bars both of which are time consuming and expensive. Template storage in tool cribs for templates of this type present a problem when inventories of several thousand templates begin to accumulate. Engineering changes are difficult to make since it means a major overhaul and reworking of the template.

Figures 5 and 6 show the simplicity of templates used for electronic tracing. The templates are rectangular, one for outside cutting only and the template shown in Fig. 6 is a rectangular windowshape. The pieces being cut are accurate and the template will duplicate this accuracy consistently. Templates of this nature are used for rectangular cutting wherein subsequent forming operations make the length a critical factor as in the cold forming of cylinders. Note the simple setup. Compare the cost of the thin template with the template used in Fig. 4. We have found that templates used with the electronic tracing device cost only $^1/_4$th to $^1/_6$th

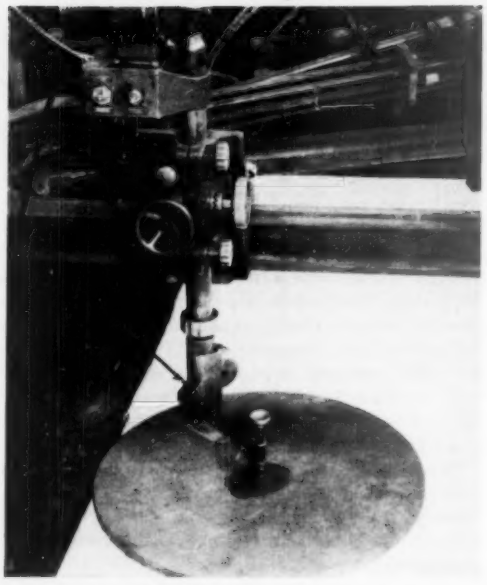

Fig. 7 Radius rod method of cutting rings on oxyacetylene flame-cutting machines

Fig. 5 Electronic tracing device following rectangular template

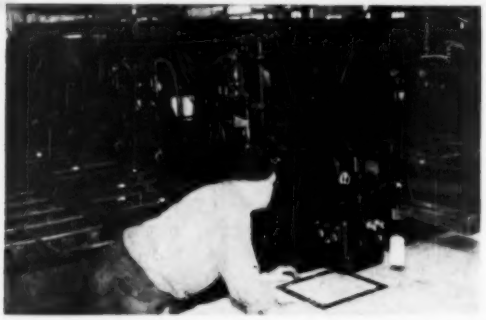

Fig. 6 Electronic tracing device following contour template on oxyacetylene flame-cutting machine

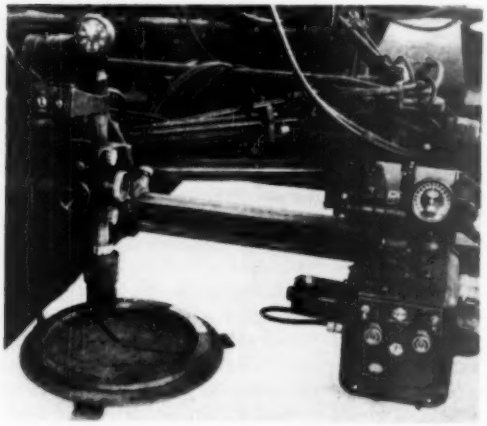

Fig. 8 Magnetized tracing wheel following inside and outside diameter

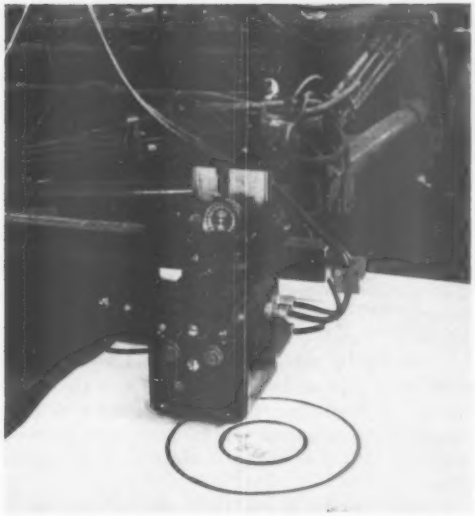

Fig. 9 Universal ring template with electronic tracing device

as much as comparable medium-sized metal templates for magnetic tracing and the cost differential increases very sharply on the larger more intricate shapes. Electronic tracing templates cost but slightly more than paper templates made for manual tracing.

Rings and disks have always presented a problem in accuracy. This is primarily due to relying on the skill of the operator in setting his machine to the proper dimension. Various calibrating devices for radius rods for both cutting tractors and shape-cutting machines have been tried but none of them overcame inaccuracies resulting from faulty measuring, see Fig. 7.

In a shop doing an infinite variety of work requiring rings it becomes imperative to use templates to gain necessary accuracy for repeat production and close fits for welded assemblies. We had built up a large variety of ring templates and had made special centering devices so that rings of various diameters could be combined to reduce the number of templates involved, see Fig. 8.

In Fig. 9 two disks are shown centered upon a small diameter pin. These disks are made from 29 ga. sheet metal. These are speedily cut on a circular speed

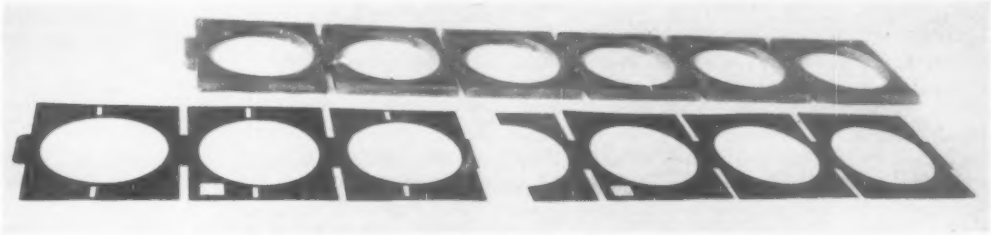

Fig. 10 Details of adjustable length template for electronic device

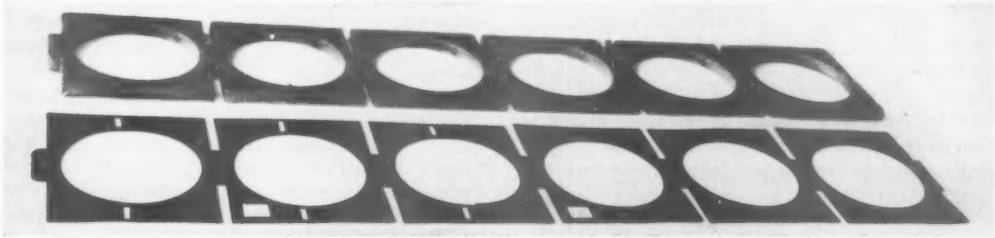

Fig. 11 Adjustable length template to full length of range

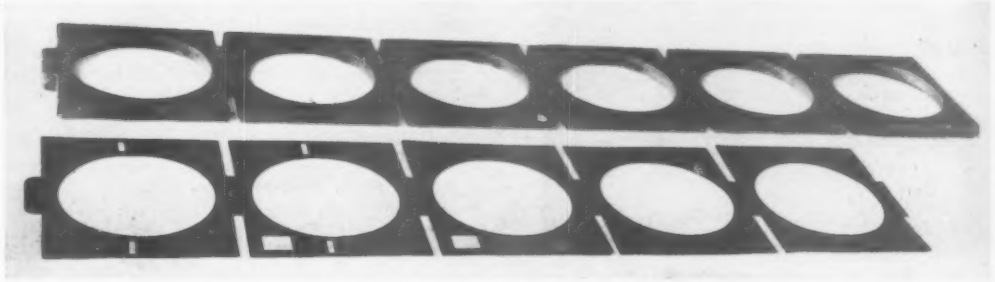

Fig. 12 Adjustable length template used with electronic tracing device

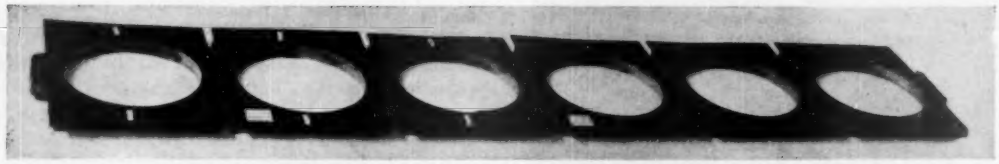

Fig. 13 Adjustable length template for electronic tracing device used as inspection template

shear around a center pin and are very accurate. The outside edge of the template has a thin band of black paint. The rest of the template surface is painted white. By preparing a series of these disks in $^1/_{16}$-in. increments it is possible to cut diameters of an infinite variety from a single series of templates. The templates are listed by diameters and a reference chart determines which template to use for cutting inside or outside diameters after making kerf allowances.

Each product has its own peculiarities of manufacture and that is true of diesel engine fabrication as it is on any other product. Diesel engines produced in multi-cylinder designs have the peculiarity of most vertical members remaining constant and the longitudinal members varying in equal cylinder spacing lengths. On designs requiring a fairly "lacy" flame-cut piece this becomes more than adding just another element since the shrinkage on a piece of this nature is not necessarily uniform. The engine deck section shown in Fig. 10 is typical. This section as shown is for a six cylinder engine. Deck sections identical in every respect are also required for 4, 5, 8, 9 and 10 cylinder engines. It became feasible to make multiple section templates so that by overlapping the maximum number of engine sizes could be cut with the minimum number of templates. A template was developed as shown which cuts 4, 5 and 6 cylinder sizes. A further extension with different shrinkage allowances covers engine sizes above the range shown. The ease of a change in cylinder spacing is shown by comparing Figs. 11 and 12. The two halves have been matched up and when secured by transparent pressure sensitive tape, and located under the plastic cover provide a flexible inexpensive template.

ADDED ADVANTAGES OF TEMPLATES

Inspection is an important factor in weldment fabrication. Inspection of weldment details before being sent to the floor for assembly and welding pays dividends in saving time and money on weldment assemblies. Inspection of flame-cut pieces can become cumbersome and often can be no better than a rough check. Shape templates from sheet metal are often used and here again is a cost saving feature of the electronic tracing device. The same template can be and is used for inspection of the piece. After allowances are made for kerf and occasionally necessary shrinkage allowances, the inspector is able to check conformity at a glance, see Fig. 13. Preinspection of the template and subsequent stamping for certification as to accuracy make flame-cut inspection cursory except for laminations and flame-cut finish.

In many cases it is possible to use the template for subsequent layout, for drilling or punching operations.

Engineering changes so costly on conventional templates are quite simple on these thin gage templates. A reduction in size is merely snipped off. An increase in size is spot welded on, the edges dressed down and the new contour cut.

SUMMARY

The electronic tracing device as applied to shape flame cutting offers the cost conscious weldry or fabricating shop these direct advantages:

1. Low first cost of both temporary and/or permanent templates.
2. Low cost of modification as product design changes.
3. Lower amount of space required for template storage.
4. Lower flame cutting costs because of ease of starting and stopping cuts with minimum repair costs.
5. Better utilization of plate material since templates of this type can be easily arranged on cutting tables to minimize scrap material between cuts.

This paper can present only a few instances, chosen to simply portray one of the more recent devices by which an alert flame-cutting shop can improve their product while reducing costs. In these days of spiraling costs and increasing competition it behooves American industry to take full advantage of the ingenuity of equipment manufacturers and production-minded technical men.

Multiple Layer Submerged-Arc Welding of Pressure Vessels

Developments of multipass automatic welding of heavy walled pressure vessels. Difficulties of flux removal overcome and optimum bead shape and size developed

by L. C. Stiles and D. H. Curry

STEEL pressure vessels are commonly welded with heavily coated electrodes, fed either by hand or by machine, and by the submerged-arc welding process. When the submerged-arc process is used, the full thickness of the joint is usually welded in two passes—one on each side. It is generally agreed this process is the most efficient yet developed for plate thicknesses of about 1 in. and that thicknesses up to 4 in. or more can be welded in two passes. However, it is also generally agreed it is not economical to use the two-pass method to weld 4 in. thick pressure vessels. Somewhere between 1 and 4 in. there are practical thickness limits on two-pass welding. The multiple layer submerged-arc welding technique has been developed to weld thicknesses beyond the practical limits of the two-pass method. While some other fabricators have developed their own techniques, this paper will describe the method as developed and used by the Chicago Bridge and Iron Co.

In 1945, because of what were considered excessive repair costs on two-pass submerged-arc welding on thick pressure vessels due to center-line cracking, experimental work was started with the idea of welding thick vessels in many thin layers. It was thought this might reduce or eliminate the cracking.

The first work was done on $2^1/_8$ in. thick A-212, grade B, firebox plate using a tlouble "U" groove and fairly heavy passes, depositing about a $^3/_8$ in. thick layer of weld metal in each pass. (See Fig. 1.) Each successive pass was centered on the weld groove and covered the full width of the groove. The side walls of the groove were undercut and the slag keyed itself into the undercut areas which made it extremely difficult to remove. When successive passes were deposited there was some trouble with slag inclusions at the edges of the welds due to failure of the weld to penetrate deeply enough into the side walls to melt the undercut areas.

Whenever this happened, a cavity resulted which of course filled with slag. Even though each layer of weld was small, as compared to weld sizes when the two-pass method is used, a considerable amount of center-line cracking occurred. This was attributed to improper bead shape which resulted in the surface of the molten pool freezing over before the center. Generally speaking, the molten metal must freeze from the bottom up, with the surface freezing last, otherwise a crack through the center line of the weld is likely to occur.

By reducing the size of the deposit in each pass, it was possible to practically eliminate undercutting and to better control the bead shape. This solved the cracking problem but the flux was still very difficult to remove. It was necessary to break it up with a peening tool in a chipping hammer, which was very time consuming and a disagreeable job. By widening the groove and further reducing the size of each bead so the fused flux would not bridge the full width of the groove, it was found most of the flux would break loose from the weld automatically. The remainder could be knocked loose with very little effort with a hand hammer. By laying narrow beads on alternate sides of the groove, it could

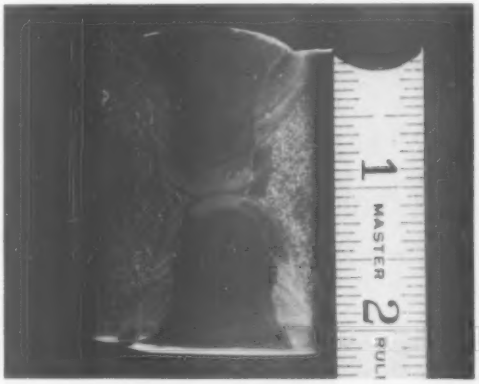

Fig. 1 Double "U" groove, $^1/_2$ in. wide, welded in relatively heavy layers, each centered on the preceding layer

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Presented at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

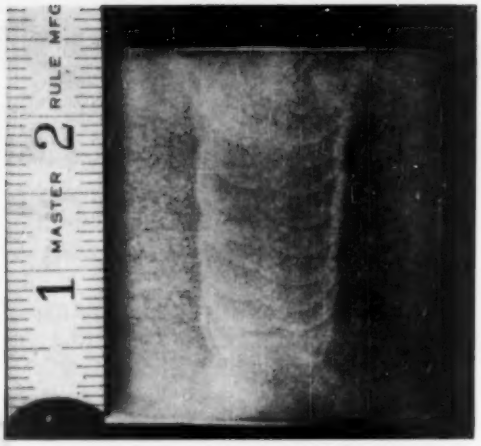


Fig. 2 Single "U" groove, 1/2 in. wide at bottom and 12° angle between side walls welded in thin, narrow layers less than the width of the groove, placed on alternate sides of the groove

be filled uniformly, and the flux removal problem was greatly reduced.

Alternating and direct currents were both tried. Both were satisfactory, but it was decided to use direct current because it was more uniform and there was a choice of polarity which might be advantageous. With the same amperage, voltage and travel speeds, reverse polarity penetrates deeper than straight polarity, but straight polarity burns off the electrode faster. Generally it was found the best results could be obtained using reverse polarity.

Groove shapes for multilayer welding can of course vary widely. It was thought the equipment on hand could be used best on the outside of vessels, so it was decided to use a single U groove on the outside. The first ones were 3/8 in. wide at the bottom and the side walls sloped at a 12° included angle. This was too narrow

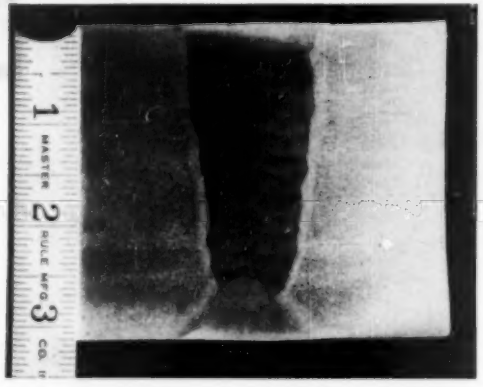


Fig. 3 Single "U" groove, 1/4 in. wide at bottom and 15° included angle between side walls

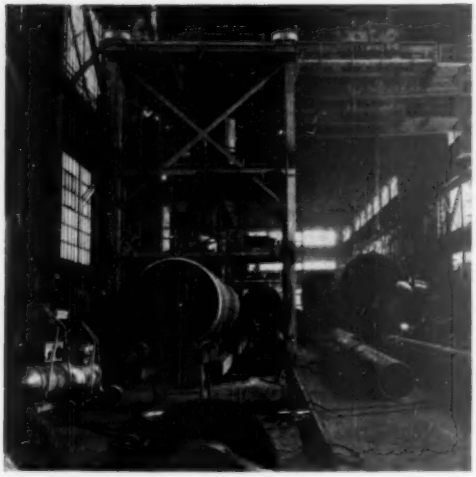


Fig. 4 Multiple layer submerged-arc welding equipment in operation

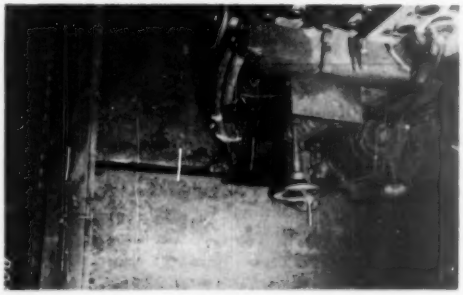


Fig. 5 Close-up of welding head and some of the push-button controls by which the operator controls all movements of the equipment and the vessel being welded as well as the welding current and flux recovery system

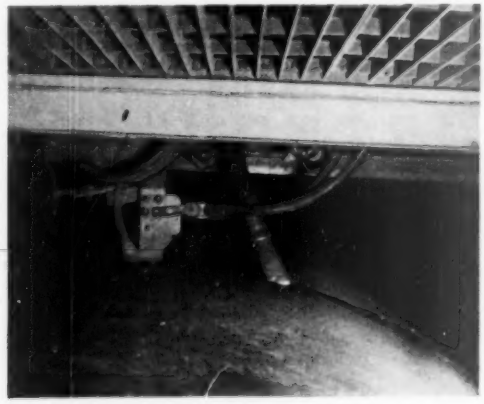


Fig. 6 Closer view of multipass welding in deep groove

Flux is fed into groove through tube at left. The electrode can be seen passing through contact jaws in center. The vacuum tube at the right picks up the unfused flux

because it was found to be difficult to keep the slag from bridging the full width of the groove even though small electrodes and low currents were used. The width of the groove at the bottom was increased to 1/2 in., which was much better. (See Fig. 2.) The width was again increased, this time to 5/8 in. at the bottom and the included angle was opened up to 15°, which is the groove finally adopted as a standard. After the main portion of the shell is welded from the outside, one pass of submerged-arc weld on the inside completes each joint. (See Fig. 3.) The last joint fitted and welded, which is commonly called the closing seam, is hand welded on the inside.

Electrode sizes have varied. Electrodes, 3/16, 7/32 and 1/4 in., have been used with currents from 600 to 900 amp. and 30 to 35 v. The kind and size of flux used depends upon the kind of electrode used and the welding current. Care should be exercised to make sure the combination of electrode and flux used will produce weld metal with the desired physicals.

Travel speeds can be varied to help control bead size and shape. For a given bead size, the faster the rate of travel the greater the welding current can be. However, there are speed limits beyond which control difficulties appear, making higher speed impractical. Speeds from 20 to 25 in. per minute have given the best results.

One of the great advantages of two-pass submerged-arc welding is the deep penetration. Roughly, two-thirds of the weld metal comes from melting the parent metal, and one-third comes from the electrode. Very small welding grooves are used, taking this into account. The multiple layer method loses much of this advantage because no great amount of parent metal is melted. Most of the weld metal must come from the electrode. Not only is it necessary to deposit much more metal when multiple layer welding, it is deposited at a slower rate because of the lower current used. Therefore, it is advantageous to use the two-pass method in preference to multiple layer welding wherever economically possible. However, the actual welding time does not tell the whole story. The time required to chip, grind, X-ray, chip out and repair defects and X-ray the repairs must also be added. A study extending over the last five years indicates that the practical upper thickness limit for two-pass submerged arc welding using a single electrode is somewhere between 2 and 2 1/4 in. on 55,000 psi. steels such as A-285, grade C or A-201, grade A, and between 1 1/2 and 1 3/4 in. on 70,000 psi. low-alloy steels such as A-212, grade B. Above these limits, it is more economical to use the multiple layer submerged-arc welding method. When welding girth seams of small diameter vessels it has been found to be advantageous to switch from two-pass to multiple layer welding at lesser thicknesses, depending upon the diameter of the vessel.

It should be pointed out that other fabricators with different equipment and methods for preparing plate edges, forming plates, fitting them together and welding the joints may find it to their advantage to use an en-

Fig. 7 10 Ft. diameter refinery tower 62 ft. 8 in. long, weighing 232,000 lb. made of 2 in. thick A-212, grade B steel being loaded aboard ship at New Orleans, La., for export to Venezuela

Fig. 8 6 Ft. diameter absorption tower 37 ft. 4 in. long, weighing 86,000 lb., made of 2 1/2 in. thick A-212, grade B steel loaded for shipment to Hansford County, Tex.

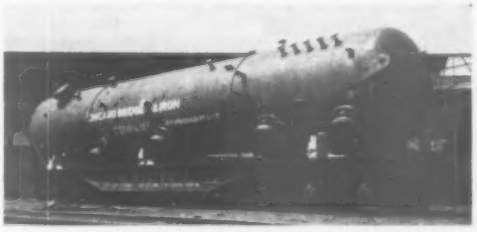


Fig. 9 8 Ft. 6 in. diameter primary resin fractionator weighing 172,000 lb., made of 2 5/8 in. thick A-212, grade B steel loaded for shipment to Rauseville, Pa.

Fig. 10 4 Ft. 6 in. diameter main absorption tower 49 ft. 7 1/2 in. long, weighing 110,000 lb., made of 2 15/16 in. thick A-212, grade B steel loaded for shipment to Sinton, Tex.

tirely different groove design, welding current, travel speed and set of thickness limits.

A great many pressure vessels have been welded by the multiple layer submerged-arc welding technique by the Chicago Bridge and Iron Co. in thicknesses up to 3 in. using equipment shown in Figs. 4–6. Figures 7–10 show completed vessels. X-ray inspection has revealed far fewer defects in multiple layer welds than in welds made by other methods. On the vessels welded during the past year the percentage of defective weld metal revealed by X-ray has averaged less than one-tenth of one per cent.

In conclusion, the multiple layer submerged-arc welding technique has been successfully used in the welding of thick shells of a large number of pressure vessels. The results, judged by both quality and cost, indicate this method is the best yet developed for general use on heavy pressure vessels.

Crack Sensitivity of Aircraft Steels

Discussion by Jay Bland

The authors have presented in this paper comprehensive results on the crack sensitivities of several grades of aircraft steels. Their choice of the circular groove weld bead specimen for determination of crack sensitivity is to be commended, as are the extensive scope and their treatment of the subject.

This discusser is particularly interested in the paper, as the results of this investigation not only add important information to the over-all problem of weld metal cracking, but confirm, to some extent, results of an investigation of medium steel weld metal conducted at the Material Laboratory, New York Naval Shipyard.[1] In view of the effects of hydrogen absorption and cooling rates on the ductility of medium steel weld metal, and upon the extent of microfissures produced therein, it is not surprising to this discusser that similar results, of obviously greater intensity, should be found for the alloy weld metal as reported in this paper.

In the referenced work, as well as in an extended treatment of the problem by Flanigan and his co-workers at the University of California,[2] which, by the way, was also presented at this Annual Meeting, it was found that the critical factor in crack formation of hydrogen-containing medium steel weld metal was the rate of cooling at temperatures below about 700° F. Flanigan has determined the influence of this rate of cooling at temperatures down to below 400° F. The postheat treatment employed by the authors would eliminate such cooling effects, and thus would minimize or eliminate cracking which otherwise would have resulted. The times recommended for postheat treatment would permit sufficient absorbed hydrogen to be evolved so as to limit or prevent crack formation upon subsequent cooling to room temperature.

An interesting phenomenon is presented in regard to Type 410 + Mo filler metal. The authors state that a postheat treatment at 600° F. is critical, as crack formation occurs both above and below this temperature. This unusual result appears to warrant additional investigation. Have the authors attempted to determine the reasons for this phenomenon? It might well be that cracking below the 600° F. treatment is due to hydrogen, whereas cracking above the 600° F. postheat may be due primarily to stresses produced by structural changes alone.

The authors also propose the concept that tying up part of the carbon as carbides will effectively reduce crack sensitivity of the aircraft steels investigated. The data presented in the paper appear to be insufficient for this particular conclusion, especially in view of their results which show that the Type 410 filler metal, in which presumably all carbon is tied up as stable carbides, exhibited the highest crack sensitivity of the group of alloys studied. In addition, the Vanadium contained in the 6130 steel basically is not much more effective in forming stable carbides than is the Molybdenum in the 4330 and 4320 steels.

With due regard for the extensive scope of the reported investigation, it still appears to this discusser that the investigation may have been extended to include metallographic examinations of the specimens. This would have provided essential information relative to such phases of the problem as types of cracks, i.e., trans- or intercrystalline, carbide influence, etc. The authors certainly have available a large number of specimens, of sufficiently varied production, as to derive considerable useful basic information on the mechanism of crack formation. It is to be hoped that they will have the opportunity to do this work in the near future.

The authors' bibliography referenced a paper by Stern, Kalinsky and Fenton which presented methods for determination of the hydrogen contents of weld metal deposits, based on work conducted at the Material Laboratory, New York Naval Shipyard. The paper, however, does not appear to include the reference, and it would be of interest to learn if the authors used this method to determine actual hydrogen contents of the various weld deposits, or merely assumed relative amounts of hydrogen possibly absorbed in the weld metal deposited by the several welding procedures used.

J. Bland is Supervisor, Welding Development Section, Material Laboratory, New York Naval Shipyard, Brooklyn 1, N. Y.

The opinions expressed herein are those of the discussor and do not necessarily represent the opinions of the Department of the Navy.

Paper by A. W. Steinberger, B. J. DeSimone and J. Stoop was published in the September, 1950 issue of THE WELDING JOURNAL, pp. 752–764.

This discusser feels that the paragraph in the paper just ahead of Acknowledgment decidedly is in error. The authors have contributed more than a "small part" to the understanding of the causes of cold cracks, and their useful and practical results cannot fail but to encourage further investigation of the basic problem.

References

1. Bland, J., "Effect of 'Quench Time' on Weld Metal," THE WELDING JOURNAL, **28** (5), Research Suppl., 216-s to 226-s (1949).
2. Flanigan, A. E., Bocarsky, S. I., and McGuire, G. B., "Effect of Low-Temperature Cooling Rate on the Ductility of Arc Welds in Mild Steel." *Ibid.*, **29** (9), Research Suppl., 458-s to 466-s (1950).

Authors' Reply

The authors appreciate Mr. Bland's encouraging discussion which is of special value in consideration of the investigations that he has conducted in this field.

The reason for the increased cracking of the Type 410 +Mo filler metal, when the critical postheat temperature is exceeded, has not yet been fully explained. It must be remembered, however, that this filler rod was deposited upon modified S.A.E. − 4320 parent metal. There is no question but that a considerable amount of the carbon and alloying elements of the base material were picked up in certain areas of the weld deposit which consequently had characteristics other than that of a true Type 410 stainless steel. Figure 25 of the published paper shows this dilution quite clearly. The darker areas represent the comparatively undiluted Type 410 material and the portions which are nearly as light as the parent metal contain a considerable amount of the base material. Note that most of the cracking occurred in the diluted areas while those regions consisting essentially of Type 410 stainless contain few if any cracks. From these observations, it is quite probable that the crack sensitivity of these deposits is related to the increase in carbon and reduction in chromium resulting from dilution with the parent metal. It would also appear that further study of hydrogen equilibrium levels at various temperatures is in order. Cracking similar to that observed with the Type 410 +Mo was also noted with the Modified S.A.E. − 4330 filler metal when cooling was arrested and postheating conducted at 1000° F.

The authors do not claim originality for the concept that tying up part of the carbon as carbides will effectively reduce crack sensitivity. Sims and Banta[1] have aptly stated, "In studying the factors which influence and control the response of steel to metal-arc welding, the principles of the conventional brand of metallurgy based upon relatively slow heating and cooling rates, or even normal heating followed by liquid quenching must be modified to suit a "high speed" type of metallurgy which is geared to the extremely rapid thermal cycles which are actually developed during welding.

"The steels with stable or large carbides which did not go into solution readily during the rapid thermal cycle and therefore behaved as lower carbon steels when welded, were found to be definitely less susceptible to cold cracking in the heat-affected zone."

Franklin[2] found that "The affinity of molybdenum for carbon is not so great as that of titanium or vanadium; furthermore, the carbide dissolves readily in austenite, and molybdenum is very effective in retarding rather than promoting the austenite transformation."

The authors agree with Mr. Bland that the investigation should be extended to include metallographic examinations of the specimens. This phase of the project is under way but has not yet progressed sufficiently for presentation.

The work of Stern, Kalinsky and Fenton in determining the hydrogen content of weld metal has encouraged the authors to conduct similar investigations with the subject aircraft steels. While the apparatus has been assembled and preliminary work initiated, it was not felt that sufficient information was yet available for inclusion in this paper. It is hoped that this program can be continued and that the resulting data can be presented at some future date.

In concluding, it is suggested that the availability of more comprehensive time temperature transformation diagrams would be of great value in furthering these studies. Curves covering the response of these steels with austenitizing temperatures in the range encountered during welding, and at various cooling rates to the isothermal temperature would be of particular interest. The extension of such curves to temperatures as low as 200° F. is needed as it appears well established that cooling rates in this range are of much greater importance than heretofore believed.

References

1. Sims, C. E., and Banta, H. M., "The Development of Weldable High Strength Steels," THE WELDING JOURNAL, **28** (4), Research Suppl., 178-s to 192-s (1949).
2. Franklin, F. F., "Use of Carbide Stabilizing Element to Improve Weldability of Plate Steels," *Ibid.*, **27** (1), Research Suppl. 20-s to 26-s (1948).

Procedure Approval Tests

How procedure approval tests were developed for weldments used in naval equipment. Representative Data Forms. Flow sheet for the performance of tests and recording results. Accomplishments

by Samuel S. Katsef

HISTORY AND PURPOSE

THE Navy shipbuilding program in 1934 was seriously handicapped because of the difficulties in producing cast carbon molybdenum alloy steel casings for cruising turbines. At that time, techniques for producing these intricate castings from the then new carbon molybdenum alloy steel composition were not yet developed. The castings contained all kinds of defects. Replacement of the defective zones by weld metal amounted to as much as 15% of the weight of each casing. At that period, foundries had very limited experience in welding. For this reason, it was necessary for them to procure suitable equipment and train personnel to perform the intricate welding operations necessary to salvage castings for cruising turbines. It was at this time that the Navy Department first applied procedure approval testing to determine whether foundries were qualified to salvage these castings in a manner which would render them suitable for Naval use. The results obtained by the application of procedure approval testing proved very valuable. It was then decided to apply this method to practically every activity engaged in the production of Naval equipment fabricated by welding.

SPECIFICATIONS FOR TESTS

In the following years, specifications for the performance of procedure approval tests were developed and tests were performed for the following materials:

(*a*) Carbon molybdenum steel castings.
(*b*) Class "An" nickel steel shafting.
(*c*) High-pressure, high-temperature steam piping.
(*d*) Copper base alloy castings.
(*e*) Carbon and austenitic steel sheets.

The welding procedures tested include the following:

(*a*) Metal arc.
(*b*) Submerged arc.
(*c*) Carbon arc.
(*d*) Atomic hydrogen arc.
(*e*) Oxy-acetylene.
(*f*) Flash welding.
(*g*) Pressure welding.
(*h*) Spot welding.

For all procedure approval testing, the method of application consisted of the following:

(*a*) The prospective contractor was furnished with the applicable specifications, if available, for the welding process he desired to qualify. Examples of representative welding data forms are shown in Figs. 1–3. If none were available, he furnished detailed specifications of the procedure he intended to employ.

(*b*) When the contractor was satisfied with the results obtained in preliminary testing, he produced the test weldment specified by the Navy Department or for which he furnished the specifications.

(*c*) Production of the test weldment was performed in the presence of a Naval Inspector who forwarded the certified data sheets together with the weldment to the Engineering Experiment Station.

PERFORMANCE OF TEST AND RESULTS

On the receipt of the materials and data sheets at the Engineering Experiment Station, a plan was prepared for the performance of a test in the form of a flow sheet. A representative flow sheet is shown in Fig. 4. The drawing, Fig. 5, presents the dissection of a carbon molybdenum alloy steel casting applied in accordance with the requirements indicated on the flow sheet. The various test specimens were then prepared and tested. From the results obtained, conclusions were drawn and recommendations made. Figures 6–10, inclusive, present the dissection patterns used in testing procedure approval weldments for propulsion shafting, pressure piping, copper base alloy castings, submerged arc welded and spot welded assemblies, respectively.

As shown on the flow sheet in Fig. 4, which typifies the flow sheets used in testing other types of weldments, the test performed included nondestructive testing.

Samuel S. Katsef is Welding Engineer, U. S. Naval Engineering Experiment Station, Annapolis, Md.

Presented at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

This paper presents the author's views and opinions which are not necessarily those of the Navy Department.

DATA FORM FOR PROCEDURE APPROVAL TEST

CARBON MOLY STEEL CASTING

CONTRACTOR'S NAME AND ADDRESS: _____ TEST NO. _____ FORM NO. 1

TYPE WELDING GENERATOR USED:
1 CONSTANT POTENTIAL
2 CONSTANT ENERGY
3 CONSTANT CURRENT
4 A.C.

MATERIAL | PLATES _____ ELECTRODES _____

DATE _____
RECORDER _____
WELDER _____
POLARITY USED _____

IDENTIFICATION SYMBOLS OF THIS WELD

PASS NO.	OPEN CIRCUIT VOLTAGE	AMP	VOLT	ELECTRODE DIA	TEMP DEG. F	REMARKS
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

1

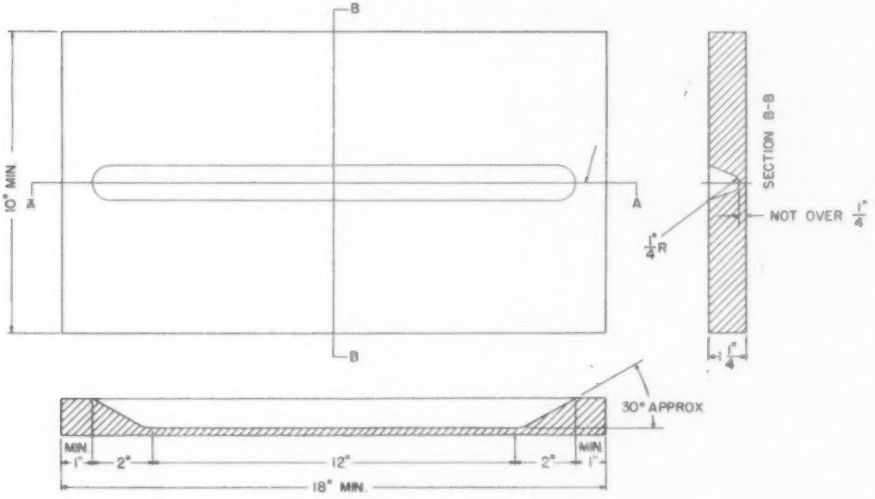
2

SKETCHES (1) AND (2) ILLUSTRATE METHOD OF FILLING IN POSITION OF PASSES.

3

FILL IN ABOVE BLANK SPACE TO INDICATE RELATIVE POSITION OF EACH PASS AS DEPOSITED.

GIVE DEGREE OF PREHEAT, IF ANY. INDICATE TEMPERATURE OF WELD METAL JUST PRIOR TO THE DEPOSITION OF EACH SUCCEEDING PASS.



SECTION A-A

NOTES:
1 THE ABOVE SKETCHED TEST PLATE IS TO BE OF ONE PIECE 10" x 18" x 1 1/4"
2 THE WELDING SCARF SHALL BE GROOVED OUT AS OUTLINED, USING FOR THIS PURPOSE TOOLS AND METHODS IDENTICAL TO THOSE USED IN PREPARING CASTINGS FOR REPAIR WELDING.
3 THE WIDTH OF THE SCARF SHALL BE SUFFICIENT TO YIELD AN ALL WELD METAL TENSION TEST SPECIMEN OF 0.505" DIA.
4 THE PLATE SHALL BE RIGIDLY CLAMPED DURING WELDING TO PREVENT WARPING TO AN ANGLE OF MORE THAN 5°
5 NO WELDING SHALL BE PERMITTED ON C-Mo STEEL AT A TEMPERATURE OF LESS THAN 300° FAHR.

Fig. 1 Welding data form, carbon moly alloy steel casting

DATA FORM FOR PROCEDURE APPROVAL TEST

COPPER BASE ALLOY CASTING

CONTRACTORS NAME AND ADDRESS

DATE:
WELDER:
RECORDER:

MATERIALS: PLATES:
WELDING ROD OR ELECTRODE:
FLUX:

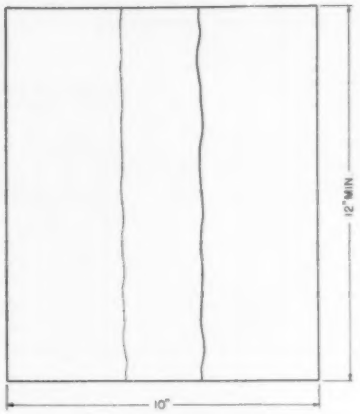
IDENTIFICATION SYMBOL OF THIS WELD:

METALLIC ARC WELDING
ELECTRODE DIA:
POLARITY:
ARC VOLTAGE:
AMPERES:
PREHEAT TEMP:

GAS WELDING
TYPE OF GAS MIXTURE USED:
WELDING ROD SIZE:
FOREHAND OR BACKHAND:
COMPOSITION OF FLUX IF OWN MIXTURE USED:

CARBON ARC WELDING
WELDING ROD DIA:
CARBON ELECTRODE DIA:
ARC VOLTAGE:
AMPERES:
POLARITY:
COMPOSITION OF FLUX IF OWN MIXTURE USED:

INDICATE THE METHOD OF MOUNTING USED.
(A) INSULATED FROM WELDING BENCH BY INSULATING MATERIAL
(B) " " " " " AIR SPACE
(C) CLAMPED DIRECT ON WELDING BENCH



HEAT TREATMENT AFTER WELDING
TEMPERATURE:
TIME:
COOLING:

REMARKS

INDICATE HERE THE RELATIVE POSITION OF EACH PASS AS DEPOSITED

REMOVE AND REWELD FROM THIS SIDE

FORM 10-20

Fig. 2 Welding data form, copper base alloy casting

DATA FORM FOR PROCEDURE APPROVAL TEST SPOT WELD

CONTRACTORS NAME AND ADDRESS

DATE
SUPERVISOR
OPERATOR

IDENTIFICATION SYMBOLS

MATERIALS USED

REQUIRED STRENGTH PER SPOT, LB.
" " PER UNIT LENGTH OF POINT, LB.
(UNIT LENGTH -)

SECONDARY CURRENT, AMPERES:

TIME, IN CYCLES:

GAUGE PRESSURE, PSI:

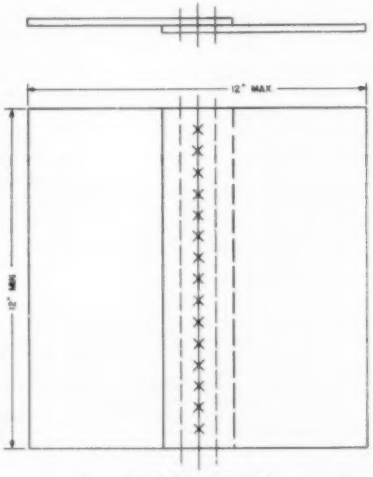
DIA. OF ELECTRODE, INCHES:

MATERIAL OF ELECTRODE:

TYPE OF CONTROLLER USED: ELECTRONIC, MAGNETIC, COMBINATION

RATING OF TRANSFORMER USED IN KVA:

TYPE OF APPARATUS USED
(A) STATIONARY, PORTABLE
(B) HYDRAULIC, PNEUMATIC, MECHANICAL PRESSURE



MARK SPACING OF SPOTS AND THE SEQUENCE USED IN THE FABRICATION OF THE WELDMENTS IDENTIFY SPOT NO 1 ON THE WELDMENTS

NOTE
1. MATERIAL, PLATE THICKNESS, OVERLAP AND SPOT-SPACING SHALL BE AS SPECIFIED FOR THE PROJECT
2. IF SEVERAL MATERIALS AND PLATE THICKNESSES ARE TO BE USED SUBMIT A WELDMENT REPRESENTING EACH COMBINATION AS PER SKETCH

Fig. 3 Welding data form, carbon steel sheets (spot weld)

FLOW SHEET

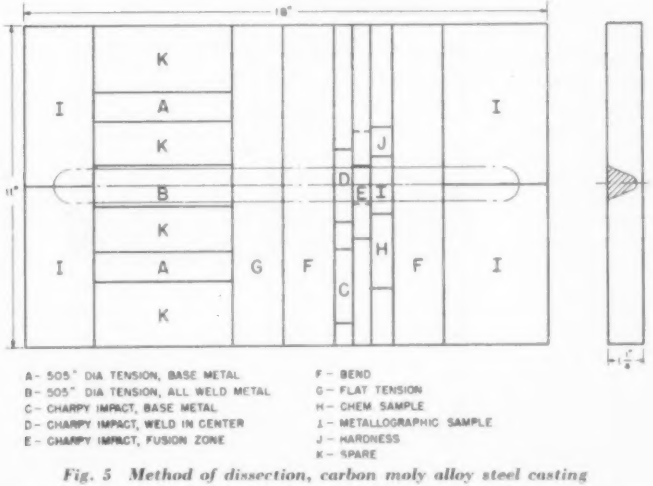
PROCEDURE APPROVAL TEST
CARBON MOLYBDENUM ALLOY STEEL TUBING

PHASE OF TEST	DATE	RESULTS REMARKS
PLAN OF WORK ESTIMATIONS		
MEASUREMENTS		
SKETCHES		
PHOTOGRAPHS		
VISUAL EXAM		
NON-DESTRUCTIVE TESTS		
DETERMINATION OF RESIDUAL STRESS		
DISSECTION OF WELDMENT		
DESTRUCTIVE TESTS (PHYSICAL PROPERTIES)		
SPECIAL TESTS		
CHEMICAL ANALYSES		
METALLOGRAPHIC EXAM		
PHOTOMICROGRAPHIC WORK		
COLLATION OF TEST DATA		
PREPARATION OF REPORT		

Fig. 4 Flow sheet

PROCEDURE APPROVAL TEST

METHOD OF DISSECTION
CARBON MOLY STEEL CASTING



A- .505" DIA TENSION, BASE METAL
B- .505" DIA TENSION, ALL WELD METAL
C- CHARPY IMPACT, BASE METAL
D- CHARPY IMPACT, WELD IN CENTER
E- CHARPY IMPACT, FUSION ZONE
F- BEND
G- FLAT TENSION
H- CHEM. SAMPLE
I- METALLOGRAPHIC SAMPLE
J- HARDNESS
K- SPARE

Fig. 5 Method of dissection, carbon moly alloy steel casting

This may consist of X-ray examination which for certain materials and conditions is supplemented by oil-powder, fluorescent or magnetic power methods of testing. These examinations constitute screen tests. If they indicate excess porosity, slag inclusions, cracks or lack of fusion, the test is suspended and the exhibitor is invited for a discussion. Referring to the results of the nondestructive tests performed, and the information given in the data sheets submitted with the weldment, the possible causes of the defects are diagnosed for the exhibitor. Thereupon, another test weldment is produced. If the nondestructive testing of the second weldment shows that it is sound, it is then dissected and the test specimens given in the dissection pattern are prepared and tested.

The tests performed to determine the mechanical properties of the weld metal are augmented by metallographic examination and hardness tests. Often, though the weld is sound, the mechanical properties of the weldment are not satisfactory. The metallographic examination usually furnishes the cue for this condition. It reveals the grain structure of each pass of the deposit and thus may be used to diagnose faulty welding techniques. The hardness test furnishes evidence, particularly for low-alloy steel weldments, whether the prescribed postheat treatment had been properly applied.

For welded pressure piping, the adequacy of the postheat treatment cannot be fully ascertained from hardness determinations. Low-carbon steels of this type of pipe material do not air harden to a considerable extent when welded under the specified preheat and interpass temperature conditions. The procedure to determine the level of the residual stress in the pipe weldment, submitted for procedure approval testing, is by the application of the relaxation method. The various steps used in this test are shown diagrammatically in Fig. 11. The measurements taken during this test are applied to compute the residual stress using the formula for curved beams in accordance with Castigliano's theorem.

For weldments intended for specific applications, the tests given above often may be insufficient to determine suitability. For such cases, special test procedures are evolved and applied. Consider the flash welded joint between 18% chrome–8% nickel superheater tube elements and the 4–6% chrome–½% moly steel nipples at both ends of the element. The suitability of the flash-welded joints was evaluated by thermo-cycling which consisted of heating the sample welds to 900° F. and then rapid cooling to room temperature. After the application of a specified number of the above cycles, all specimens

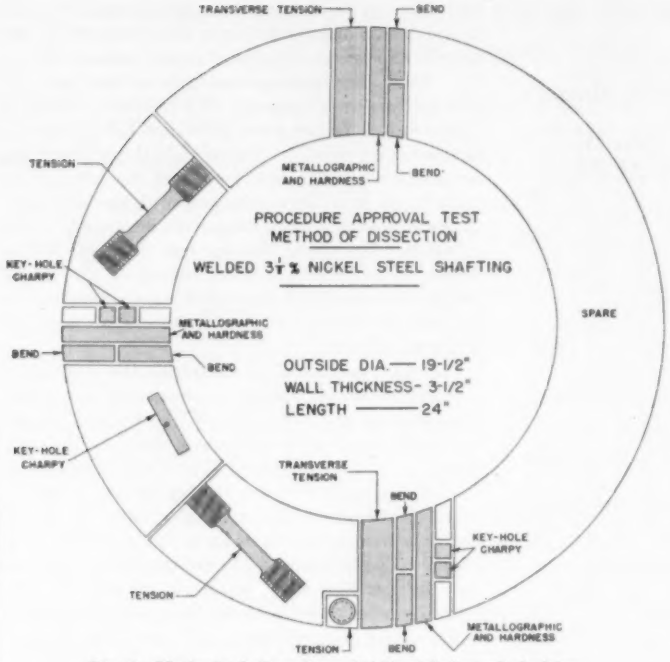


Fig. 6 Method of dissection, 3½% nickel steel shafting

were examined by an applicable method of nondestructive testing. A portion of the samples was tested in static tension. The remaining samples were tested dynamically in alternating rotary flexure. The specimens were set up as cantilever beams with the joint at the reaction point. A special fixture containing ball bearings was applied at the free end of the beam. There the load was suspended at the end of a spring of suitable characteristics.

In evaluating the welding procedure for manganese bronze castings, when the intended application is to salvage propellers, it is important to know whether the postheat treatment applied was effective. Microscopic examination of etched weld sections and hardness testing in this material do not fully reveal the effectiveness of the low-temperature 850° F. postheat treatment. These materials are subject to stress corrosion, particularly in view of the fact that in the weld zone a fringe of beta structure develops regardless of the application of the specified preheat of 600° F. or 700° F. The test applied to determine whether or not the postheat treatment was effectively applied, is by immersing a portion of the weldment in mercurous nitrate solution. After a period of immersion, the weldment is removed from the solution for examination of crack development at the fusion zones.

Certain brazed and pressure-welded pipe joints cannot be fully evaluated by the performance of static tests. The joints are evaluated by determining their endurance value in alternating torsion. Thus the joint efficiency under that method of testing can be quantitatively compared with that of unwelded base metal. If there are no data available for the endurance value of the base metal, it is then determined concurrently with testing the weldments.

LEGEND
A = FACE BEND SPECIMEN
B = ROOT BEND SPECIMEN
C = METALLOGRAPHIC AND HARDNESS SPECIMEN
D = TRANSVERSE TENSION SPECIMEN
E = RELAXATION TEST SPECIMEN
F = SPARE

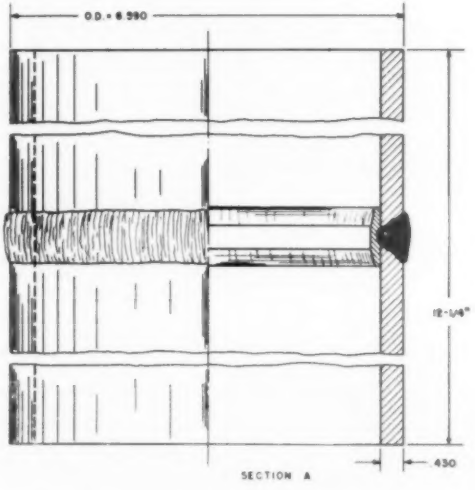


Fig. 7 Method of dissection, carbon moly alloy steel piping

PROCEDURE APPROVAL TEST
METHOD OF DISSECTION
REPAIR WELDING OF
MANGANESE BRONZE CASTING

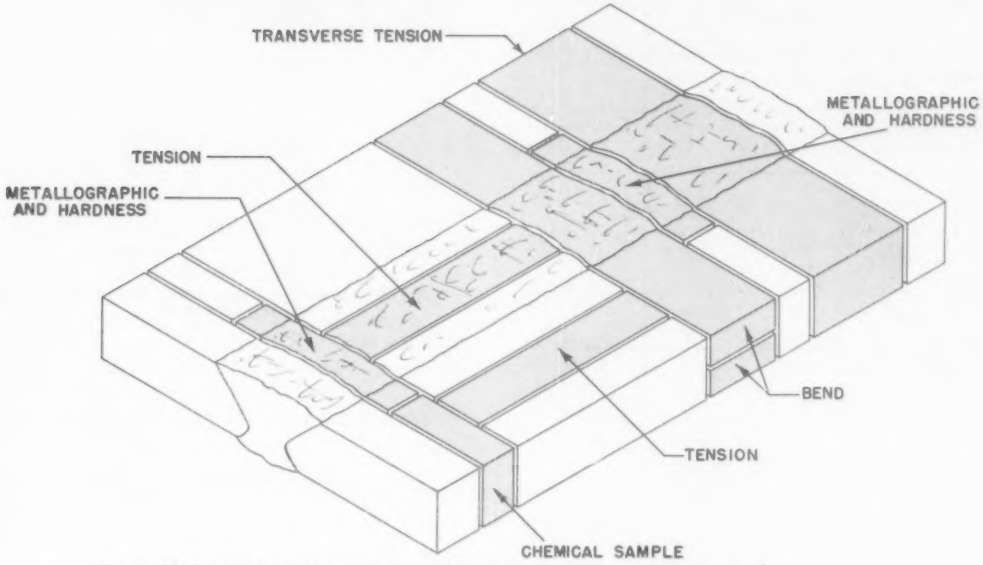
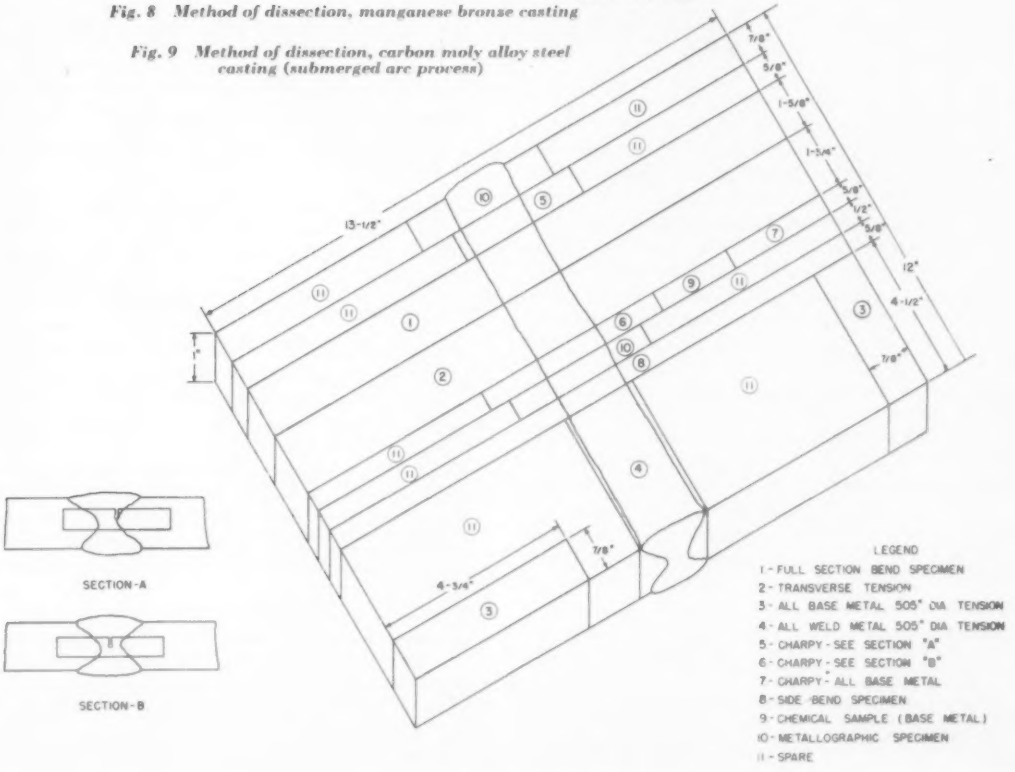
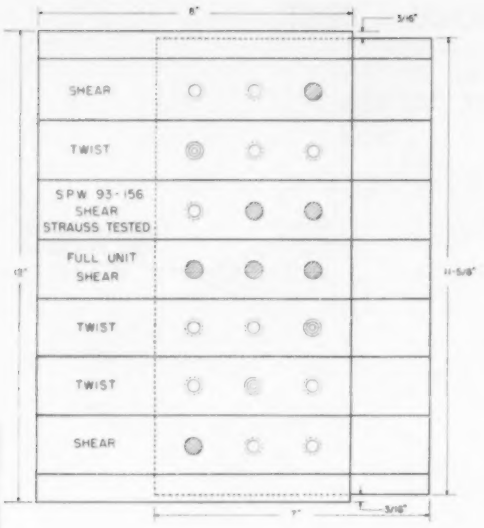


Fig. 8 Method of dissection, manganese bronze casting

Fig. 9 Method of dissection, carbon moly alloy steel casting (submerged arc process)





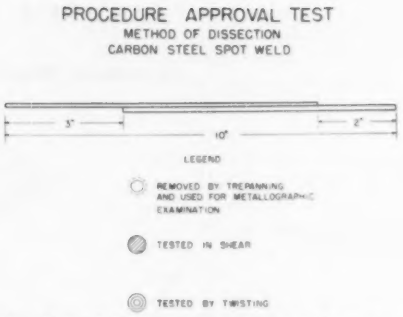
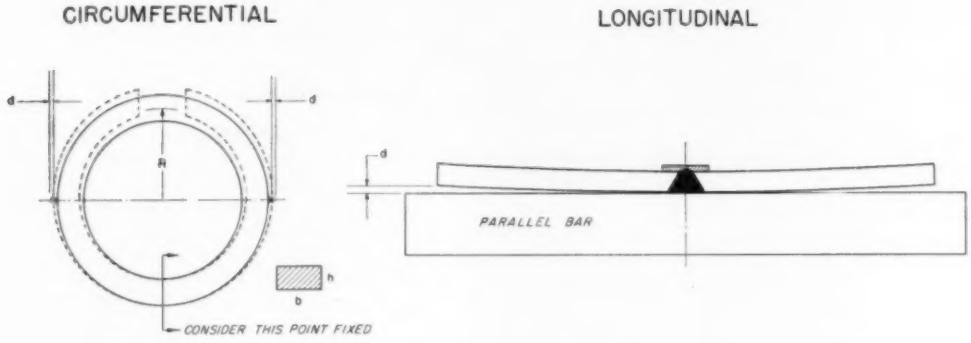


Fig. 10 Method of dissection, carbon steel sheet assembly (spot weld process)



DEFLECTION FOR A CURVED BEAM IN ACCORDANCE WITH CASTIGLIANO'S THEOREM IS:

$$d = \frac{\pi P R^3}{4 E I} \qquad (1)$$

FROM WHICH P, THE LOAD TO DEFLECT A UNIT LENGTH OF THE TUBE IS:

$$P = \frac{4 E I d}{\pi R^3} \qquad (2)$$

THE STRESS IN A BEAM IS:

$$S = \frac{PL}{M} \text{ or } P = \frac{SM}{L} \qquad (3)$$

WHERE L = R

SUBSTITUTING VALUE OF P IN (2)

$$S = \frac{4 E I d}{\pi R^2 M}$$

S = AVERAGE CIRCUMFERENTIAL STRESS IN SECTION (p.s.i.)
P = LOAD TO DEFLECT A UNIT LENGTH OF TUBE
E = MODULUS OF ELASTICITY (30,000,000 p.s.i.)
I = MOMENT OF INERTIA ($bh^3/12$)
d = DEFLECTION OF ONE QUADRANT
R = ORIGINAL MEAN RADIUS OF TUBE
M = SECTION MODULUS ($bh^2/6$)

THE LONGITUDINAL STRESS IS COMPUTED FROM THE FORMULA APPLICABLE TO CENTRALLY LOADED, FREELY SUSPENDED BEAMS

$$d = \frac{PL^3}{48 E I}, \text{ FROM THIS}$$

$$P = \frac{48 d E I}{L^3} \text{ AND}$$

$$S = \frac{PL}{4M} = \frac{48 d E I}{4 L^2 M}$$

S = MAXIMUM FIBER STRESS (p.s.i.)
d = DEFLECTION IN BEAM (inch)
P = CONCENTRATED LOAD (pounds)
L = LENGTH OF BEAM (inch)
E = MODULUS OF ELASTICITY (30,000,000 p.s.i.)
I = MOMENT OF INERTIA ($bh^3/12$)
M = SECTION MODULUS ($bh^2/6$)

Fig. 11 Computations for residual stress

ACCOMPLISHMENTS OF THE PROCEDURE APPROVAL TESTS

The tests are designed to yield information concerning the factors which contribute toward the production of welds satisfactory for the intended applications. The tests performed furnish information concerning:

(*a*) Joint design.
(*b*) Welding technique.
(*c*) Preheat temperature.
(*d*) Interpass temperature.
(*e*) Postheat treatment.
(*f*) Composition of the weld metal.

The extensive and searching tests mentioned above are performed to obtain reliable information concerning all components of the above factors. The reason for such extensive testing is that the objective is not merely to determine whether the procedure examined is acceptable or not. The objective is to learn all deficiencies and advise the contractors not only what they were, but primarily how to eliminate them consistently.

Thus, procedure approval testing by the U. S. Naval Engineering Experiment Station is a means to disseminate basic information, the ultimate objective of which is to assure for the Naval Service the widest source of qualified fabricators.

SUMMARY

From the above, it is evident that the role of procedure approval testing as applied by the U. S. Naval Engineering Experiment Station is a real contribution in converting welding from the level of an industrial art into a scientifically controlled fabrication procedure.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Bela M. Ronay, Superintendent of the Welding and Electrical Laboratory, U. S. Naval Engineering Experiment Station, Annapolis, Md., and J. Henri Siegel, Head of the Welding Branch, Welding and Electrical Laboratory, U. S. Naval Engineering Experiment Station, Annapolis, Md., for their kind assistance in the preparation of this paper.

Latest Developments in Koldwelding

by William Dubilier

THE Koldweld process, a method of cold-pressure welding without the use of heat or electricity, was made available in this country late in 1949 by Koldweld Corp. of New York, and immediately created a tremendous interest throughout the American metal-working industry.

Developed by the General Electric Co., Ltd. in England (not associated with the General Electric Co. of the United States), this revolutionary process of cold-pressure welding is applicable to all nonferrous metals, particularly aluminum and its alloys. The required welding pressure can be applied manually or by power tools. Only the simplest tools are required, and their use does not demand special training or the employment of skilled labor. Welds of uniform excellence are produced easily, quickly and at an unprecedented low cost.

The versatility of the Koldweld process permits its exceptionally wide application in the metal-working industry. The Koldweld process not only economically replaces other assembly methods in many industrial applications, but produces stronger and better welds. It usually permits additional savings in manufacturing costs through simplification of designs to take full advantage of the special characteristics of the Koldweld process which have no parallel in other welding methods.

As a result of the numerous inquiries investigated by the Koldweld associates, several new applications of the process were developed, greatly broadening the field where Koldweld can serve the industry. Some of these new applications are illustrated and described here.

William Dubilier is President, Koldweld Corp., New York, N. Y.

TRAP WELD

Several kitchen utensil manufacturers queried Koldweld concerning welding screw studs to the sides of utensils for the attachment of knobs and handles. The required welded stud assembly was intended to replace the riveted assembly, which often becomes loose in use because of the heating and cooling cycles to which it is subjected.

This led to the development of the Koldweld trap weld, which proved to be superior to the older methods from the standpoint of strength and ease of application, as well as lower costs. The screw stud or a threaded insert is now, in effect, integral with the utensil. (See Fig. 1.)

The fabricated metal form has a metal insert firmly

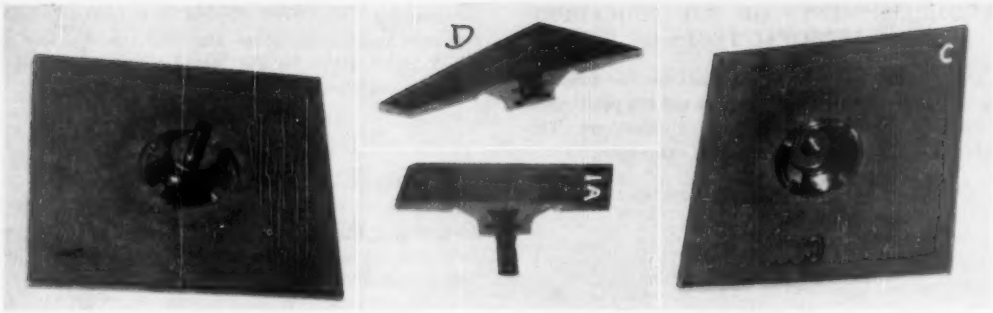


Fig. 1 Typical trap weld

The base formed by the same Koldweld tool, but with a threaded insert or with the thread molded directly into the aluminum base, is shown at *C*; *A* shows a cross section of the trap weld with its screw stud and extra large thickness of the base. With the aid of the Koldweld process the equivalent of plastic molding is produced in nonferrous metals without the application of heat; *C* shows the threaded aluminum base with a hobbed ¼-in. thread formed during the welding operation. The threading is obtained by molding the base around a steel screw, then removing the screw and leaving the threads inside the base; *D* is the cross section of a threaded insert molded into base metal

embedded into another metal structure without the use of any applied heat or electric current, by a quick and simple process using two metal parts (Fig. 1 (*A*)). This is an excellent example of how Koldwelding can be applied to produce all-metal objects by pressure only.

Similarly, different types of metal inserts or parts can be molded between dissimilar nonferrous metals. For example, a thin steel insert, such as a sheet or wire netting, could be molded within aluminum sheets.

The trap weld is also used to produce the female counterpart of the screw stud. Several methods were developed (Fig. 1 (*C*)), and in each case the back of the work remains smooth.

The standard ferrous 10–32 thread screw stud shown at *A* (and in cross section at 1 (*A*)) was tested with tensions up to 1500 lb., when the steel stud broke outside of the weld (see Fig. 2). Although the welded joint showed distortion, it did not break, and the joint remained airtight and moisture proof. It is interesting to note in the curve (Fig. 2), that the Koldwelded joint was not distorted until tensions of one-half ton, or 1000 lb., were reached. This stud showed a strength equivalent to that of many rivets, so that handles could be attached to utensils or other products by one simple stud instead of a number of rivets. The stud base is designed with depressions to accommodate the molded handle to prevent twisting, as shown in Fig. 1 (*A*).

A steel insert can be trap welded in a similar manner. The insert is constructed with shoulders, as shown in the cross-section view of Fig. 1.

It should be noted in the curve that there is a very slight distortion of the aluminum sheet, beginning at the load of about 600 lb. At 1000 lb., the distortion is twenty thousandths of an inch (0.02). These tests show that this type of Koldwelding joint will withstand more than three times the tension required to produce the same distortion in a standard stud weld or rivet. The increased strength of material is a result of the pressure applied in forming the Koldweld joint. The distortion was then increased to 0.18 in. without breaking the Koldweld joint. The steel stud broke at a load of more than 1500 lb.

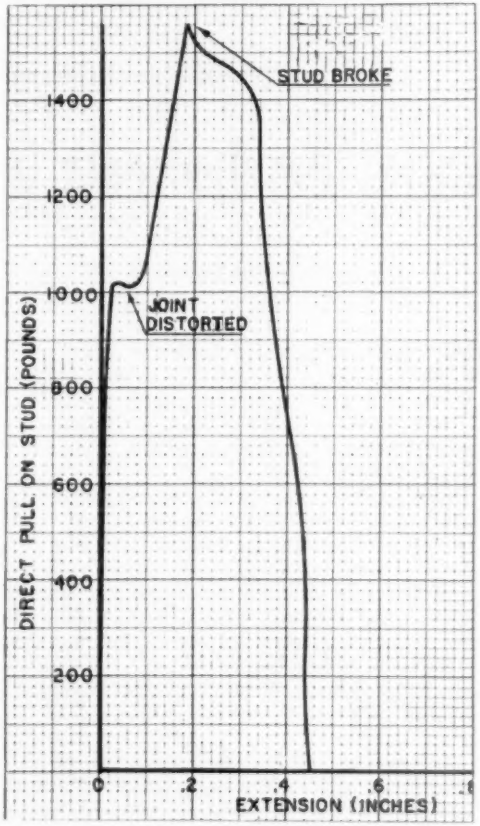


Fig. 2 Under a tension of 1500 lb. the standard 10–32 thread screw stud of the trap weld broke, but the welded joint showed only distortion and remained airtight and moisture proof

Fig. 3 Shows both sides of a wave welded joint

These tests show the great improvements possible with Koldwelded joints employing a single stud or a single threaded insert compared with rivets, and without any possibility of the joint loosening after long periods of time in service.

Where it is necessary to make attachments to a body or a container usually made of nonferrous sheets, where moisture proof or pressure tightness is required Koldwelding is the most convenient way of applying such attachments. Where rivets or gasketed joints may ultimately develop leaks (for example, in pressure compartments for stratospheric operation), it also is the ideal method for making attachments to the inside of the body, for it leaves the outside smooth, flat and streamlined.

WAVE WELD

In many applications involving welding of flat stock the standard straight-line weld was sometimes found undesirable because of structural or esthetic considerations. To overcome these objections, the wave weld was developed (Fig. 3).

This wave weld is applied with the same ease as the regular straight-line weld. It is somewhat stronger as a result of the wave line intersecting the grain of the metal. The finished work has no tendency to bend or buckle along the weld line.

The tools for making this type of weld are very simple, and consist of one-shaped element pressing against a flat plate.

STAGGER WELD

It has always been difficult and sometimes impossible to weld comparatively thin metal sheets to heavy bar stock, such as encountered in the construction of truck bodies, tanks, railroad cars, metal shelving, shelters and the like. This was solved with the development of the stagger weld (Fig. 4). The tools for making this type of weld are the simplest of all, and, as described in the wave weld, consist of a shaped element pressed against a plate.

In the stagger weld a number of dots or short straight-line welds are slightly staggered so that they lie along two or more parallel lines. The welds are formed with a special tool applied to the thin sheet side of the work.

SANDWICH WELD

Serious objections were made by various fabricators to the indentations on the surface of the work produced by the application of the pressure welding tool. The objections were for the most part on the grounds of appearances; in some cases, when a smooth-finish surface of the finished work was required, the grounds were technical.

The first new development to overcome these objections was a new type of weld where the indentations appear on one side of the weld, the other side remaining smooth. Tests have shown the new weld to be somewhat stronger than the weld with indentations on both sides.

The next step was the development of a method where a third piece of metal was used to fill up the indentations, the three pieces being welded together in a single operation. This proved satisfactory and eliminated the pressure-tool indentations on both sides.

The ultimate development was the sandwich weld

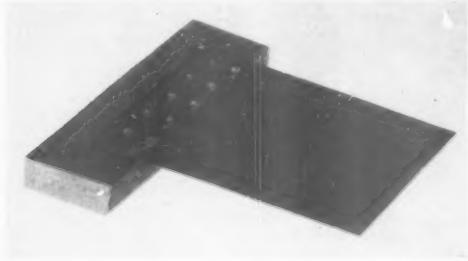


Fig. 4 The stagger weld for welding thin metal sheets to heavy bar stock, consists of staggered dots or straight-line welds on two or more parallel lines

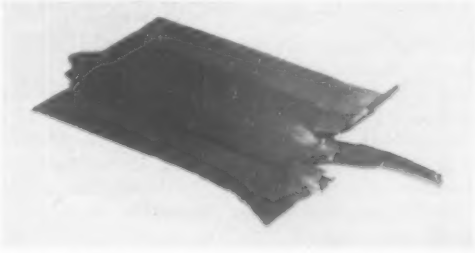


Fig. 5 A piece of wire being used as the third, or filler piece in a sandwich weld

During the welding operation the wire flattens out between the sheets, producing a wide and strong weld area, without indentations on either side

(Fig. 5). In this the third piece of metal is sandwiched between the two workpieces, and all three welded together in a single operation.

LAP WELD

An especially interesting problem was submitted by a Government department, which required the manufacture of large thin-walled sheet-metal boxes or containers. The containers had to be airtight and moisture proof, and made out of single sheets. The limited quantities involved did not justify the construction of the large and expensive tools.

A slight redesign of the container blank permitted the sides of the container to overlap slightly (see Fig. 6), and the overlapping sides lap welded to produce the finished container shown, with the resulting lap weld at the strength of 130% of the original material.

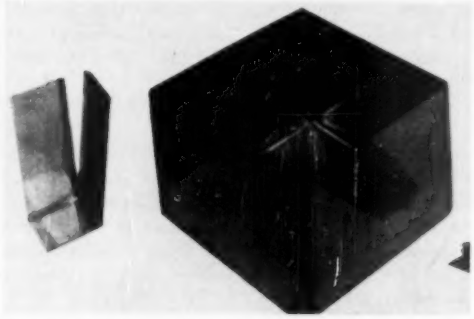


Fig. 6 Lap weld in a thin wall sheet-metal container, the weld being 130% of the strength of the original metal

When boxes are made from thin sheet metal and heat applied during its manufacture, the sides usually warp and become misshaped and various strains develop which cause distortion. This working tendency was completely eliminated by the heatless Koldweld process.

One simple tool-structure design enables the same corner welds to be used for boxes or containers of any size, reducing the heavy casts and large cumbersome tools required for press operations.

KOLDWELD ELECTRICAL CONTACTS

Among numerous problems investigated by the General Electric Co., Ltd. laboratories for the benefit of manufacturers of electrical devices, several deserve special mention.

Silver electrical contacts, riveted or silver soldered or brazed to copper or brass bars, are subjected in operation to extreme heat cycles because of arcing. With time, the bond between the contact and the bar is destroyed or loosened.

A simple operation now permits permanently Koldwelding small or large silver and other metal contacts for switches, circuit breakers, relays and the like. (See Fig. 7.)

Fig. 7 Shows a small silver contact welded to a copper strip

The Koldweld process can also be used in welding heterogeneous nonferrous metals, so frequently required in the electrical industry. Commercial copper, pure electrolytic copper, beryllium copper, brass, silver, aluminum, lead, nickel and their alloys, including Monel, are easily Koldwelded each to the other.

It is now possible to Koldweld extremely thin nonferrous metal sheets (10 mils and less) by using a simple small hand tool (Fig. 8). This is not practical with heat-welding methods.

WIRES AND CONDUCTORS

With the Koldweld process it now is possible to make various welds on different conductors. (See Fig. 9.) These include a two-conductor cross weld, welding a small copper wire to a copper-clad steel rod, welds of two conductors—of the same or dissimilar metals—ferrous and nonferrous, stranded conductors, pigtailing a conductor and so on.

The Copperweld Steel Co., who supply heavy copper-clad steel rods for grounding purposes, have developed, under a license from the Koldweld Corp., a very efficient method of connecting their conductors, making perfect contact as shown at *B* in Fig. 9, where a copper-clad steel rod has welded to it a small copper wire.

Fig. 8 Thin nonferrous metal sheets now can be Koldwelded with a simple hand tool

A—A two-conductor cross weld, made in a single operation by a Koldweld tool

B—Koldweld of a small copper wire to a copper-clad steel rod

C—Aluminum or copper conductors, trimmed

D—Aluminum or copper conductors, untrimmed. If desired, the flashing can be left on, for it adds to the structural strength of the joint

E—A weld of two conductors, copper or aluminum. The Koldweld joint between two similar conductors has a smaller electrical resistance than the conductor

F—The Koldweld joint between two stranded copper conductors

G—A method of pigtailing a conductor to a rod with several turns of the conductor around the rod, to reduce mechanical strain on the weld (compare with Fig. 1 (*B*)).

H—The weld of an aluminum conductor to a copper conductor of the same diameter. The Koldwelding produces a perfect bond between the two metals, as shown in the microphotograph of the cross section of the weld in Fig. 10

I—Two copper conductors welded together. Aluminum and copperclad steel conductors are welded together in the same manner

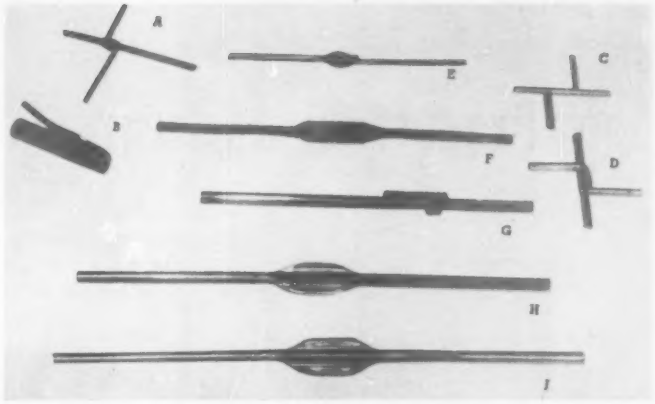


Fig. 9 Various welds on different conductors:

It is interesting to note that although the pressure was sufficient to distort and displace the steel conductors, a thin layer of copper was always present and the welding took place between the two copper surfaces. The weld proved to be mechanically stronger than the wire itself.

OTHER APPLICATIONS

Many other uses for Koldweld have been found in various fields. A simple tool has been developed for joining thin metal sheets or strips to increase the length of plate for continuous runs without retreading. Koldwelding can also be used for increasing the length of coiled metal for continuous processing.

Cans and other containers made from 0.010-in. aluminum are being developed for an oil company. These containers will have a rectangular shape, which has a great advantage in affording flat surfaces for printing and display advertising.

Large tubes have been made for a musical instrument manufacturer, to replace the former extruded resonator tubes used in xylophones, which heretofore had to be polished and carefully handled. With Koldwelding, these tubes can now be manufactured from well-finished sheet-metal stock.

Round wooden dowels or rods have been covered with thin-gage aluminum sheet by Koldwelding process. This method will find many other useful applications.

For packaging or sealing various electrical and other units in airtight, moisture-proof thin-walled aluminum containers, Koldweld methods have been found to be both inexpensive and satisfactory.

Collapsible tubes, such as used for toothpaste and so forth, are end sealed by Koldwelding to produce a more satisfactory seal and prevent the contents from seeping through the normal double-edged fold. This

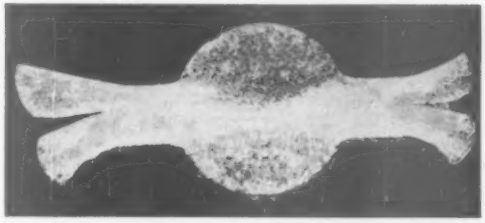


Fig. 10 A photomicrograph of aluminum and copper wire Koldwelded together, which shows how their facing halves fuse and flow out into welded flaps at each side

Koldwelded tube can be used successfully for oils, perfumes and other compounds marketed in collapsible containers.

Aluminum bottles can easily be made by extruding the bottle upside down, leaving the base open. The base is then closed by Koldwelding a circular disk.

Aluminum cored cables have always given difficulty in joining the aluminum conductor.

In fixing thin plates such as covered plates to castings and/or heavy frames, Koldwelding will be found very useful in many structures, such as radio chassis and other portable units.

Koldwelding has been successfully applied by a well-known safety razor manufacturer, and his new product may soon appear on the market.

A number of companies are experimenting with joining conductors quickly and easily in the field. Two types of tools have been developed, one for light wires up to 0.048 in. diameter and the other for wires up to 0.144 in. in diameter.

Continued application study, by General Electric Co., Ltd., Koldweld, and their licensees, constantly adds improvements, adds to the ever widening field of the Koldweld process applications and testifies to its remarkable versatility.

New Production Applications of Hard Facing

With automatic and semiautomatic equipment speed of production, uniformity and quality are improved. The inert-gas-shielded-arc welding process offers several advantages

by E. C. Hurt

WHILE patents on the art of hard facing were first applied for as early as 1896, it was not until almost 30 years later that hard facing was recognized as an industrial tool. But from that time on, it has become increasingly important throughout industry as one of the most economical means of protecting parts from wear.

The most recent advance in the use of hard facing, of course, has been the mechanization of many production applications of the process—that is, where large quantities of similar parts are involved. When automatic or semiautomatic equipment is used to apply the hard-facing material, the deposit can be made faster and it takes less skill on the part of the operator. Also, finishing operations are less expensive because deposits are more uniform.

Another major development that has helped to broaden the usefulness of hard facing was the introduction of the inert-gas-shielded-arc welding process. With this method, an excellent bond is obtained between the deposit and the base metal, yet there is not much dilution of the hard-facing alloy. No flux is needed because the shield of inert gas protects both the electrode and the puddle and thus prevents oxides from forming.

STEAM VALVE INDUSTRY FIRST TO MECHANIZE

The first to put mechanized hard-facing into practice was the steam valve industry. Because of the trend toward higher pressures and temperatures, hard-facing alloys were adopted to protect the seating surfaces of the valves from heat, wear and corrosion.

Figure 1 illustrates a hard-facing machine in operation, surfacing a 24-in. diameter gate valve ring. The groove to be faced is $^1/_8$ in. deep x 2 in. wide. The

Figure 1

average time for facing this size ring is 40 min. Approximately 130 cu. ft. each of oxygen and acetylene, and $6^1/_2$ lb. of hard-facing rod, are used during this operation. This compares with a daily production rate of only four rings, when the same size ring was surfaced manually, using $10^1/_4$ lb. of hard-facing alloy and 110 cu. ft. each of oxygen and acetylene per ring.

In this particular instance, the ring is mounted on a variable speed positioner. Multiple-flame heads are provided for preheating the body of the ring and other multiple-flame heads for applying the hard-facing alloy. Each head is mounted on an individual holder and adjustments can be made both horizontally and vertically. The rods are gravity-fed, and there is a slight oscillating motion of the welding assembly. This machine can be used for hard facing seat rings and disks, ranging in diameter from 6 to 30 in. Figure 2 shows a seat ring after hard facing and machining. The setup in Fig. 3 is for surfacing an 8-in. diameter gate valve disk. The disk shown in Fig. 4 has been hard faced, but not finished.

E. C. Hurt is Welding Engineer, Haynes Stellite Division, Union Carbide and Carbon Corp., Kokomo, Ind.

Presented at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

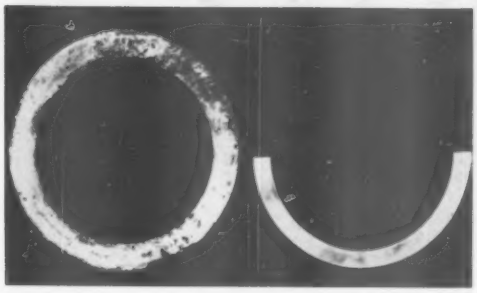


Figure 2

REJECTIONS CUT WITH MECHANICAL SETUP

In addition to steam valves, many other types of valves are also hard faced to prolong their life under severe service conditions. Since cobalt-chromium-tungsten alloys resist corrosion and erosion, and retain their hardness at high temperatures, it was only natural that these alloys should be adopted as hard-facing materials by manufacturers of gasoline motors and Diesel engines. At the present time, hard-faced valves or valve seat inserts are standard equipment in many aircraft, trucks, buses and industrial engines.

Most of these valves and valve seat inserts are hard faced mechanically by what is known as the "rotary" method, illustrated in Fig. 5 (both the equipment and process are covered by patents). The machine consists of a ten-spindle table that can be indexed on a predetermined time cycle. Generally, there are three working stations—preheating, welding and postheating. Sometimes, in hard facing the larger size valves, an additional preheat station is required. The hard-facing

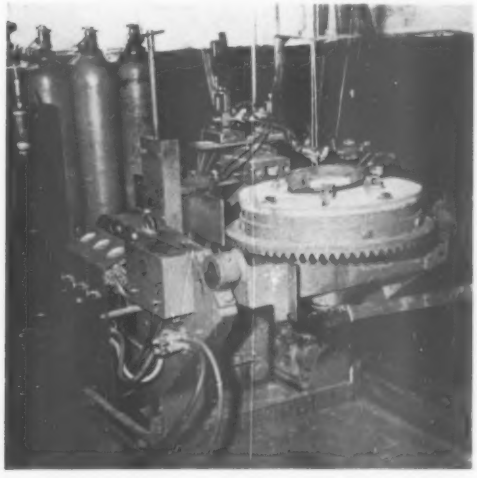


Figure 3

Figure 4

rod is fed under the flames at the welding station by a mechanical device and is controlled so that the proper amount of rod is melted each time. Figure 6 illustrates the head and rod feed arrangement. This machine is the nearest approach to a fully automatic machine so far designed. However, because of the many variables, maximum results depend considerably on the skill of the machine operator. When the proper setup for a given size valve or valve seat insert is established, rejections seldom run over 2% even after the most rigid inspection. The production rate will run from 40 to 100 pieces per hour, depending on the size of the valve or valve seat insert. Figure 7 shows a hard-faced valve that was in operation for 714,000 miles.

In the oil and food-processing industries, there is a widespread demand for hard-faced cylinders for use as pump sleeves, bushings, collars and rolls. The machines that have been developed to do this work satisfactorily and economically are usually referred to as "cylindrical" machines. (This equipment and process are also covered by patents.)

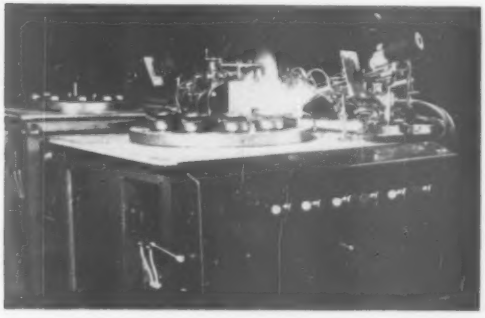


Figure 5

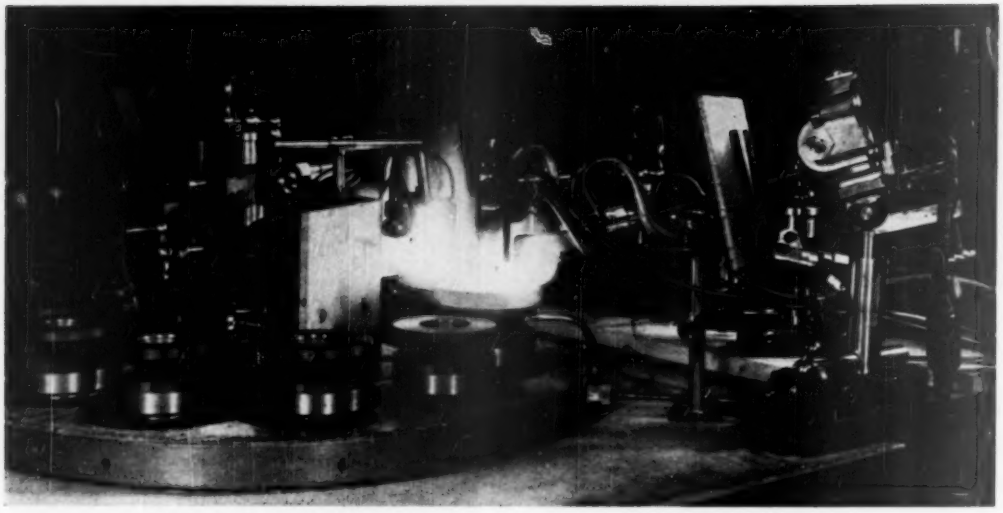


Figure 6

HARD FACING WITH CYLINDRICAL MACHINE

Figure 8 illustrates one type of cylindrical machine that is being used to hard face a stainless steel pump plunger, $6^1/_4$ in. O.D. x 54 in. long. The hard-facing alloy is being applied in 9-in. long sections with spaces 2 in. wide between each section. These spaces are used as locating points for determining the straightness of the plunger. They are filled in by hand after a rough-machining cut has been taken on the outside surface. On this particular job, a total of 50 lb. of metal was applied in less than $^1/_6$ of the time that was required for a manual application.

The heads provide two parallel rows of converging flames. Between them is a rod guide with a series of holes spaced $^3/_8$ in. apart. The rods feed by gravity through the guide holes. The converging flames impinge on the rod just above the point of contact with the work. The molten puddle is maintained on top of the rotating cylinder and must solidify before the cylinder rotates far enough to cause the metal to run off. However, there is very little difficulty in this respect after the proper heat balance has been obtained to conform with the rate at which the cylinder turns. The entire table supporting the rotating spindle is designed so that the workpiece may be oscillated lengthwise. This slight oscillation helps to overcome the furrows that may develop on the surface between the individual rods. There are also various adjustments incorporated in the machine to compensate for work of different sizes.

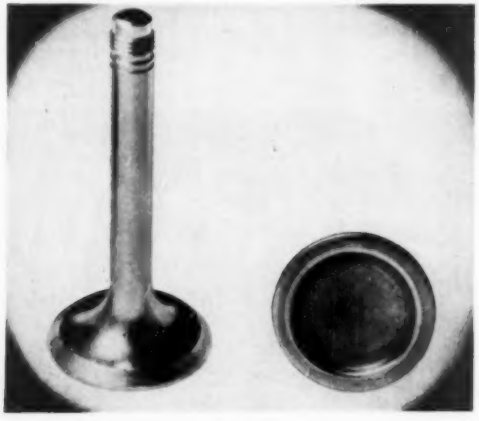


Figure 7

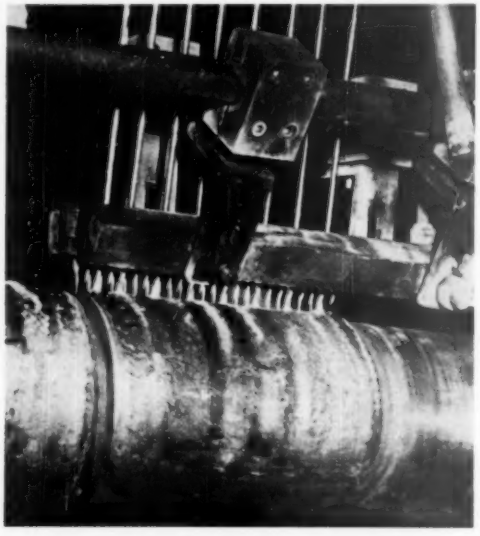


Figure 8

Figure 9

Figure 9 shows still another type machine that hard faces the outside surface of a large Capstan ring or pull block. Much the same method is used as was just described. The ring is 26 in. in diameter x $6^1/_2$ in. wide. A deposit $^3/_{16}$ in. deep is applied in one pass. Approximately 40 lb. of alloy is deposited in two hours' welding time. Figure 10 is a view of the ring before hard facing, and Fig. 11 shows the ring after the deposit was made.

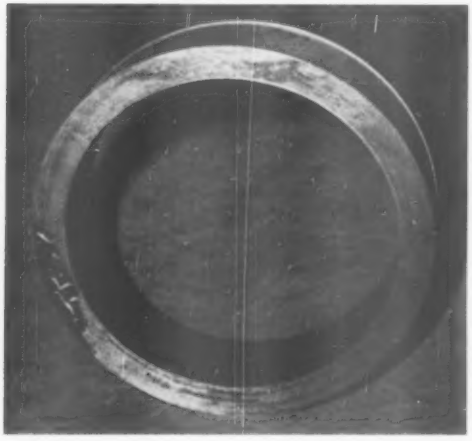


Figure 10

Another method recently developed involves the mechanized hard facing of the tapered flight of a conveyor screw (Fig. 12). Screws of this type are used for processing asbestos, coal, cement, sulphur, and other similar abrasive and corrosive materials. This particular screw flight is approximately 16 in. wide at the bottom, tapering to 8 in. at the top. The total length of the spiral flight is about 35 feet. The deposit, which is approximately $^1/_8$ in. deep, progressively decreases in

Figure 11

width from $2^3/_4$ in. at the bottom to $^3/_4$ in. at the top. Total welding time was $5^1/_2$ hours.

OSCILLATING PLATFORM USED

For hard facing the screw flight, the rod-feed motor and both welding and preheat heads are mounted on an oscillating platform. The oscillating unit itself is mounted on a bracket that can be moved in or out to compensate for the taper. The entire mechanism rises at a speed that is adjusted to maintain the heads and rod in the proper position in relation to the pitch of the

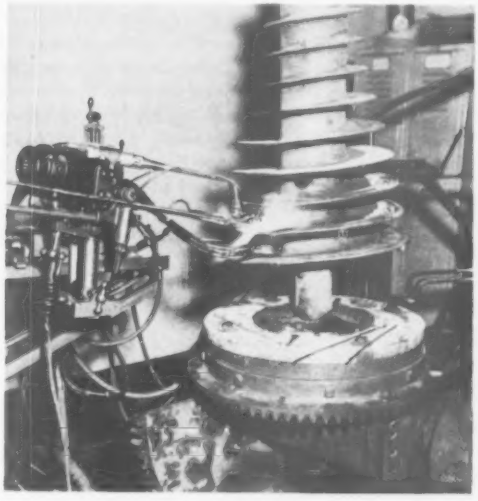


Figure 12

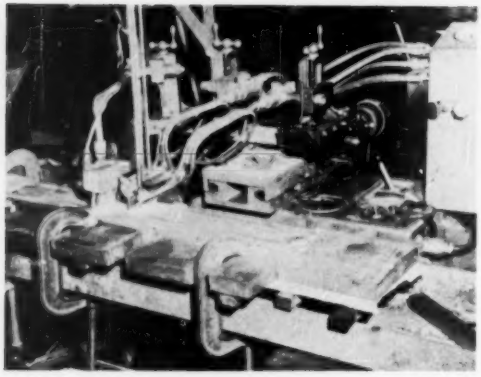


Figure 13

flights. The rod feeds under the welding head and is melted off and distributed by the flames as the heads move slowly back and forth. The length of stroke is determined by the desired width of the deposit.

The straight-line method of hard facing is basically the same as that described for steam valve applications. There may be some difference in the preheat head arrangement, but the welding head arrangement is identical. The same slight oscillating motion and gravity rod feed are used.

The hard facing of pulp shredder knives is a good example of the straight-line method (Fig. 13). These blades are 1 in. thick x 8 in. wide x 27 in. long. The hard-facing alloy is applied on the cutting edge in a groove that is $^1/_8$ in. deep x 2 in. wide. Average welding time is 20 min. for the application of $2^1/_2$ lb. of alloy.

TYPICAL JOBS USING SHIELDED-ARC WELDING

The inert-gas-shielded-arc welding process previously mentioned has only recently been introduced into the hard-facing field. However, applications that have already been made have indicated that there are many instances where this new process can be used to advantage. A West Coast fabricator, for example, used it successfully for hard-facing the wearing surfaces of a conveyor screw for a cotton seed press. The deposit was made at a rate of 3 lb. per hour, whereas the average rate with the process previously used was $1^1/_2$ lb. per hour.

Another particularly successful application of the process was for hard facing the cutting edge of hot shear knives with nickel-base alloys, such as Hastelloy alloy C. The high red hardness of this alloy, combined with its easy machinability and work-hardening characteristics, make it an excellent material for this type of service.

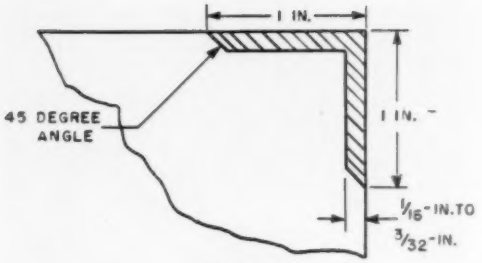


Figure 14

A steel manufacturer is applying Hastelloy alloy C on hot shear blades that are 4 in. wide x 6 in. deep x 60 in. long. Figure 14 is a drawing of the corner cross section of one of the blades. Every effort is made on this job to obtain as little dilution as possible. The alloy is applied at an unusually high rate, and the final deposit is fine and smooth. The department foreman estimated that 269,000 tons of hot steel, 3 to 5 in. thick, were cut with one set of blades. This same company has also found Hastelloy alloy C superior to other hard-facing materials for entry guides, twist-guide rolls, and other parts subjected to thermal shock.

This same alloy is also recognized as an excellent material for hard facing hot-trimming and punching dies. It resists thermal shock and does not have a tendency to chip or spall, as is common with many hard-facing alloys. Hastelloy alloy C may be applied by oxyacetylene, metallic-arc, or inert-gas-shielded-arc welding. A hard-faced die is shown in Fig. 15.

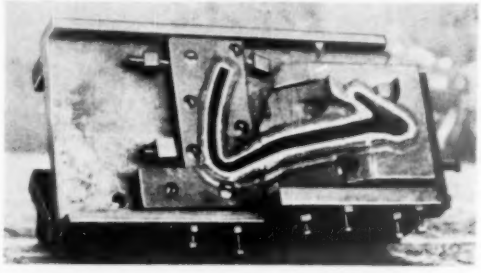


Figure 15

We have mentioned here only a few of the many applications and methods of production hard facing that have proved successful. Naturally, there are many more, and research and development work is constantly being carried out to help industry find other applications where hard facing could also be profitably applied to prolong equipment life.

Flash Welding Nonferrous Materials

Discussion by Charles Bruno

All flash welding requires excellent alignment of the finished product. Not only is alignment required in the interest of the finished product but also because the process demands it. Misalignment results in uneven heating of the ends of the workpieces and telescoping or sliding of one piece over or on the other. On thin extended sections or shapes this is prohibitive. Nonferrous metals demand closer alignment than ferrous materials because the nonferrous has relatively less strength and is much more likely to telescope when hot.

Ferrous materials will accommodate wider platen openings and still resist telescoping. Nonferrous metals demand relatively narrow platen opening, therefore more accurately cut workpieces. Of course the work must be perfectly aligned in the dies before the weld is made and alignment must be maintained through to the finish of the weld. This means that not only dies but also platens on which dies are carried must be accurately aligned.

These machine components, particularly the work-holding clamps, must be substantial and designed to withstand the upset forging force of the push-up mechanism without noticeable deflection. The thinner or more extended the work section, the closer the machine tolerances become.

It has been proved that most nonferrous materials may be held in steel dies thereby permitting much greater die life and maintenance of alignment. The steel dies may be copper plated or tinned to prevent rusting and to insure good electrical conductivity in the secondary circuit.

The dies should be water cooled in most cases so thermal conduction can carry away heat picked up from the work. High production dies are designed so they can be made easily replaceable and still have sufficient physical strength.

"Pinch-off" dies have been developed for aluminum. These dies permit as little as 0.005 in. final die spacing and pinch the upset metal to a point where it falls off or where it may be readily knocked off. The pinch-off dies not only facilitate the removal of the upset metal but also improve the weld technique and permit more consistent welding of materials usually difficult to weld.

An extremely fast upset at completion of the flashing cycle produces a very narrow weld zone and very little heat-affected zone adjacent to the weld. The weld zone may be as small as 0.0005 in. Also high-tensile heat-treated aluminum alloys may be flash welded with relatively little loss in strength.

The "pinch-off" dies are made by releaving or cutting back at an angle the face of the dies that face each other across the platen opening. These dies are sharpened to a very sharp edge and on the final closing of the die the spacing may be as small as 0.005 in.

The dual pressure upset arrangement contributes to high-strength welds. This dual pressure is designed so that the cutoff of current may be adjusted from a short time (a few cycles) before the first upset to a short time after the second upset.

Both of these pressures are individually adjustable. In dual pressure welding, the flashing action is snuffed out by a relatively fast moving, low force upset. This low force and high current are maintained for a few cycles (60 cycle reference timing) and then heavily forged.

Two such machines have been designed by the Thomson Electric Welder Co. and have been operating in our plants for over a year and a half; operation at the rate of 1200 mitered welds per 8-hr. shift producing 300 windows. The dies have been working satisfactorily three shifts per day at an average of 10 days at which time it is then necessary to resharpen the pinch-off dies.

The machines operate at 100-psi. line pressure on the clamps and the push-up pressure; 10 psi. on the accumulator pressure. Excessive metal splatter must be cleaned from the dies prior to placing a new part in the machine to be welded. This is done by using an air valve on the end of a flexible hose which hangs on the front of the machine. The operator removes the excess flash from the dies by blowing compressed air over them.

Air line pressure is not permitted to drop below 75 psi. If the air pressure does drop below 75 psi., poor welds will result because of insufficient upset pressure.

The properly designed "pinch-off" dies may be machined several times to extend the life of the dies. They are machined to an angle of about 30°.

The current stops when the final push-up starts. The second push-up travels at very low speed and at the end of its travel the "pinch-off" blades have a space of 0.005 in. During this travel all the additional flash is pinched off due to the shape of the dies.

The traveling distance of the second push-up is approximately $^1/_8$ in. That, of course, is controlled by the thickness of the metal being flash welded. The alumi-

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Charles Bruno is Welding Engineer with the Reynolds Metals Co., Louisville, Ky.

The paper by F. L. Brandt was published in the September 1950 issue of THE WELDING JOURNAL, page 718.

num window frame sections are locked in the jaws and held securely by a pin inserted through the section. This is to prevent the section from sliding in the dies during the flashing action. Forging pressure applied is approximately 10,000 psi.

This type of machine has been operating very successfully with a very minimum of rejects in production. Rejected parts run 1% maximum.

Discussion by Jerry Martin

I have been asked to comment on the paper by F. L. Brandt on "Flash Welding Nonferrous Materials" published in the September 1950 issue of THE WELDING JOURNAL.

In preparing a discussion of another man's work it is always desirable to limit one's self to comments on the applications he has made in production. Therefore, you must keep in mind that all our applications have been in the manufacture of window sash involving aluminum alloy 63ST5 in 90 degree corner welds, or miter welds if you prefer.

Mr. Brandt has done a very able job in presenting a comparison of the equipment and procedures used to flash weld ferrous and nonferrous materials. This is especially true in light of the small number and scattered geographic location of these nonferrous applications.

I heartily agree that more production applications are not being made principally because of a lack of "know-how." His paper should help considerably in disseminating information about newly developed techniques and applications.

There is little that can be added to Mr. Brandt's statement of alignment tolerances and general equipment specifications other than to say that they are correct in all respects. Not only close tolerance dies but accurately aligned and substantially designed machine components are a must if acceptable welds are to be produced. Our experience of the past 6 months proves that a flash welding machine meeting all of the requirements set forth by Mr. Brandt has produced good commercial quality welds at an entirely satisfactory rate. Sample welds, when tested to destruction, have consistently failed through the parent metal in the portions of the section which are normally held horizontal during the welding operation.

Steel dies have proved satisfactory for aluminum applications and they need not be hardened but should be of good quality steel. If copper plating or tinning is employed it should never be applied to those surfaces in contact with the section to be welded or adherence will be encountered. The technique of inserting a thin copper sheet between the die and the platen has solved our contact problems without the use of plating or tinning.

Water cooling of the dies has not been necessary even with the production rates of 150 welds per hour.

We have had "pinch-off" dies in operation for approximately 4 months with excellent results. However, 40,000 welds before dressing is an enviable figure. "Pinch-off" dies will slightly decrease the production rate because of the necessity of extreme die cleanliness. However, in comparison to the saving in clean-up time this loss of production is insignificant. Deterioration of the "pinch-off" edges seems to result from electrical arcing rather than from heat or pressure or both. This arcing could result from improper setup particularly in the realm of the current cutoff variable. However, we have found that when pinch-off dies are employed the balance between the variables, i.e., secondary voltage, flashing speed, flashing distance, amount of upset and current cutoff is not nearly so delicate as it is when pinch-off dies are not employed. This contributes substantially to production weld quality and reduces setup time.

We have had no experience with the dual pressure upset arrangement so do not feel qualified to comment further.

Discussion by C. R. Dixon

Mr. Brandt has brought out several interesting facts in his paper any of which can be discussed at length when related to the flash welding of aluminum and its alloys. An interesting discussion could be centered around his oscillogram, Fig. 7. Examination of this oscillogram shows that during the last four cycles of flashing the platen was traveling at a velocity of 0.53 in. per second, 0.0249 sec. (1½ cycles) later the platen velocity was 12.9 in. per second. The reason Mr. Brandt obtains such good results in the flash welding of the aluminum alloys may be attributed in large part to this rapid change in velocity or acceleration from flashing to upset.

It is known that joint efficiencies of from 80 to 90% can be obtained in wrought-aluminum alloys with a flashing velocity up to 2 in. per second, and upset velocities up to 5 in. per second. However, the welding schedule is rather critical and considerable care must be taken to maintain the constant schedule.

With the acceleration that Mr. Brandt can obtain in his machine, the welding schedule should be less critical. This is particualrly so if the upset current heat may be reduced to a minimum, in other words, by cutting the upset current dwell to 1 or 1½ cycles, I would expect little or no trouble in getting joint efficiencies higher than 95% in 61S-T6, 24S-T3 and 75S-T6.

G. E. Martin is Plant Engineer with the Fentron Steel Works, Seattle, Wash.

C. R. Dixon, Alco Process Dev. Labs., New Kensington, Pa.

Copper Alloy Brazing for Production Economy

New braze-welding practices and a new fluxing procedure cut down the time required for joining and finishing assemblies of thin steel

by C. E. Swift and E. B. Brown

FABRICATORS of light gage steel are finding new production speed and economy through the use of braze welding. Reported savings of 20 to 40% are realized by the use of modern low fuming bronze welding rods, larger torch tips and new automatic flame-fluxing devices. Braze welding is also accomplished with copper-silicon welding rods and the inert-gas arc or carbon-arc methods. These savings are based on costs which include investment in equipment, preparation of parts for braze welding, welding time and material and the cost of finishing.

Too often the selection of a joining process may be largely influenced by the availability of equipment that happens to be in the shop doing the job. The first thought is to use existing equipment and skills without a study of all applicable methods. It may prove to be more economical to dispose of existing equipment, or even let it stand idle, than to use it on certain jobs. A cost study of each joint is usually necessary to determine this.

It is best to consider joining problems during the early stages of product design. In fact, the very choice of metal used may be influenced by the cost of joining it. Some metals are difficult to resistance weld or metal-arc weld. But all of the ferrous, nickel and copper alloys are readily braze welded. Combinations of these metals can be used to obtain the most desirable properties in each part of an assembly. Braze welding should be considered for joining any of these metals in thicknesses under $^3/_{16}$ in.

When considering braze welding, it is easy to think of a number of very real reasons for using this process. The first cost of the equipment is usually low, about $250 for each operator and it can be less on small installations. This figure would include automatic fluxing equipment for mixing a volatile flux with the acetylene gas.

Joint design for braze welding is simple. It is applicable to square and vee butt joints, lap, fillet and T-joints. Practically any joint can be braze welded. Fit-up of joints is not critical, relatively wide gaps can be bridged and still develop good strength and appearance. Usually no special preparation is needed. It is not necessary to add metal for lap joints, as in spot or seam welding. Of course, as in all other welding, it is best to remove grease, rust or heavy mill scale in the weld area. Fixtures for braze welding can be very simple. As the torch is light and easily moved around an assembly, braze welding can be done in all positions.

Operators soon develop the simple technique required for using torch tips two or three sizes larger than customarily used for the same thickness of steel. With flame fluxing and the large torch tips, the operator appears to be brushing the bronze on the joint. The high torch heat and continuous cleaning accomplished by the flux in the flame, practically eliminate the need for preheating. Welding speeds are similar to those attained in metal-arc welding.

Little bronze is used on each joint. The smooth joints obtained require practically no excess metal for finishing. Every pound of rod can be used; there are no flux losses, spatter loss or stub ends to throw away.

The greatest savings in braze welding with low fuming bronze or nickel silver are usually realized after the joint is made. Butt joints are smooth; they require little if any grinding. Fillets are evenly formed and feather out perfectly at the edges and corner welds are well rounded. It is rare that either of these joints are ever touched after braze welding. The use of flame fluxing greatly reduces, or eliminates, the job of removing excess flux before finishing operations. Some users just dip the assemblies in the rust-proofing solutions.

In carbon-arc braze welding with copper-silicon welding rods, no flux is necessary, so cleaning after welding is limited to wire brushing. The quick, concentrated heat of the arc combined with the lower melting point of the copper-silicon alloy, makes a joint in a minimum of time with practically no distortion.

Manufacturers have tested many joints production braze welded with low-fuming bronze. The strength of these joints consistently exceeds the strength of the steel base metal. In some cases a nickel-silver brazing alloy, also low fuming, has been used to develop maxi-

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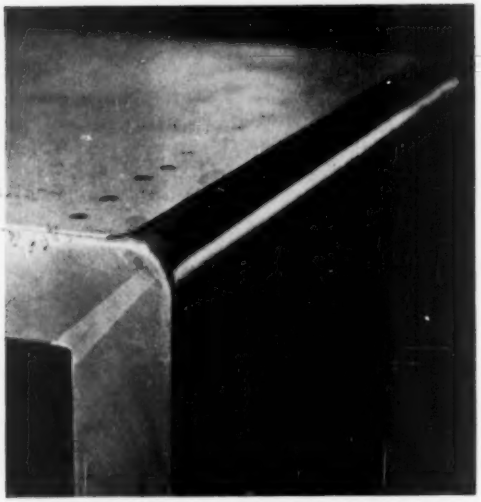

Fig. 1 Steel bedside cabinet showing the corner as braze welded and sanded

Note the wide gap bridged with the bronze, permitting a generous tolerance in notching and forming the corner

Fig. 2 A finished steel bedside cabinet

The braze-welded corners are smooth and the large flat areas of the sides are free from distortion

mum strength where unusually high stresses are involved. Carbon-arc or inert-gas arc brazewelding of steel is done with copper-silicon alloy or silicon bronze welding rods. These joints develop the strength of the sections being assembled.

There is practically no limit to the field of applications for braze welding. To date it has enjoyed particularly wide acceptance in the metal furniture industry where it is used on beds, chairs and cabinets. It is also widely used on bicycles, automobiles, refrigerators, furnaces and household appliances. It is used wherever formed sheet metal, structural tubing or small solid shapes are joined. Let us look at some typical examples.

A prominent metal furniture manufacturer uses oxyacetylene welding for many of the most important joints in their cabinets, beds and hospital equipment. In Fig. 1, we see the braze-welded corner of a bedside cabinet. In notching the sheet steel, ample tolerance

Fig. 3 A bed panel corner, braze welded and sanded

All depressions have been filled with bronze to eliminate any need for soldering to provide a smooth contour

Fig. 4 These brackets and tube intersections on a lounge frame were tacked in a fixture

The operator completes the joints with the oxyacetylene flame and a low-fuming bronze welding rod

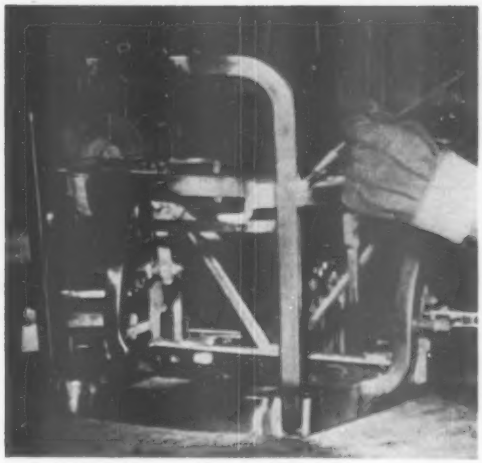

Fig. 5 All the joints on this desk chair are braze welded

After tacking in a fixture, the chair is positioned on a bench for the best braze welding conditions

is allowed to avoid any chance of overlapping after forming. Note the wide gap that was bridged with the low-fuming bronze. The sound bronze weld metal is easily smoothed off for finishing. Figure 2 shows the completed cabinet with a fine enamel finish concealing the braze welds in the front corners.

At a difficult corner on a bed panel, Fig. 3, the formed sheet steel is braze welded to a square steel tube stiffener. Here the bronze is used not only to strongly tie the two parts together, but in the same operation all the low spots are filled in. One sanding smooths off the weld area ready for painting. It is never necessary to go back with solder to fill in the low spots.

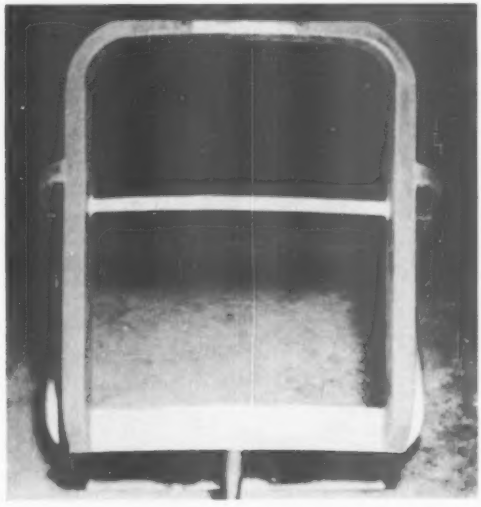

Fig. 6 The office chair frame is complete

No sanding of the smooth fillets is necessary. The flame fluxing used for braze welding leaves no beads of excess flux to be removed

Furniture made from steel tubing offers many opportunities to save with braze welding. Low-fuming bronze and flame fluxing combine to make quick, smooth fillets around all types of joints. Figure 4 shows brackets being braze welded to a lounge frame in which round tubular sections have already been joined. No sanding of these fillets is necessary. They are ready for painting.

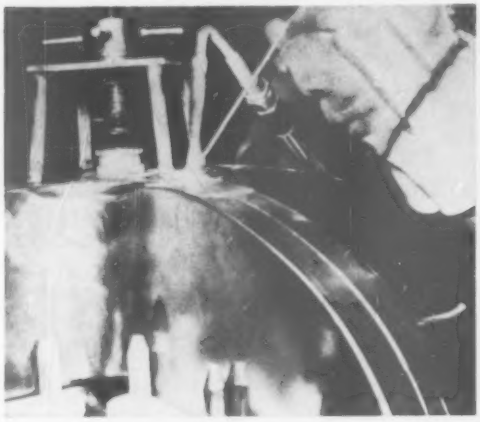

Fig. 7 A cloverleaf plate holds the four legs of an office swivel chair together

It is braze welded to the formed steel legs with low fuming bronze. The fine, smooth fillets need no further finishing

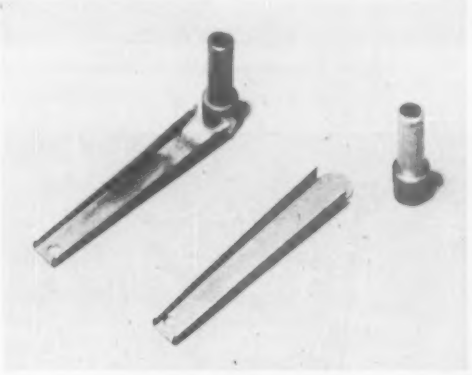

Fig. 8 A crank handle is made from a steel stamping and a machined tube

These parts are braze welded with a high strength, low fuming, nickel-silver welding rod

In Fig. 5, we see a chair made from square steel tubing being braze welded. It is tacked in a fixture, then moved to the table where it is quickly positioned and the joints completed. Figure 6 shows the completed frame. The smooth fillets need no further attention before going to the paint shop.

Components of the base of a steel office chair are being braze welded in Fig. 7. The cloverleaf plate is attached to the spreading legs with a bronze fillet. There is no

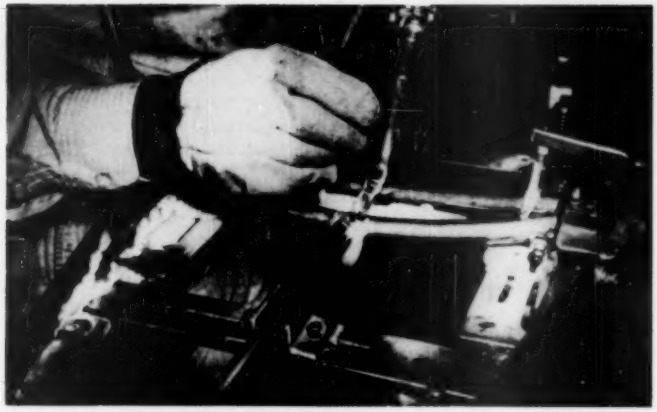

Fig. 9 Handles for power lawn mowers have to be rugged
This one is braze welded with high-strength nickel-silver welding rod

ture, as many other products are braze welded. In Fig. 9, a lawn mower handle is shown being brazed with the high-strength nickel-silver alloy. A neat, small fillet is obtained, Fig. 10, which develops the full strength of the tubing and requires no special cleaning before painting.

Braze welding with the carbon arc and a copper-silicon welding rod is used to fabricate steel rods to make tote baskets for handling automotive parts. By braze welding, the baskets are ready to galvanize without the work of removing welding slag and spatter. In Fig. 11, the welder is braze welding a rod intersection. Figure 12 shows the finished baskets.

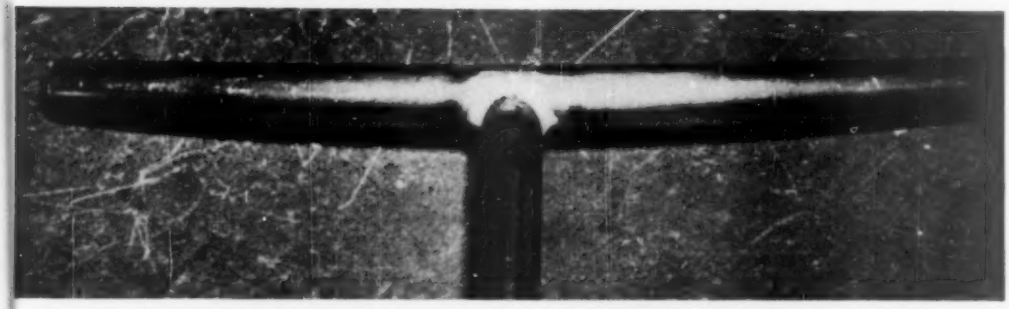

Fig. 10 This power mower handle shows the neat fillet obtained by braze welding with nickel silver
It can go from the welding shop to the paint shop

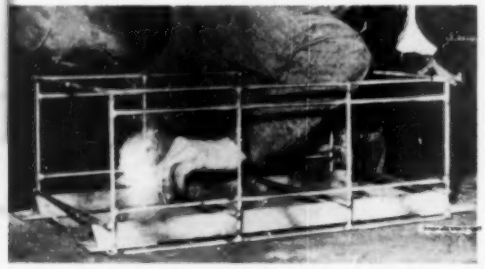

Fig. 11 A tote basket, made from steel rods, is carbon-arc braze welded with a copper-silicon welding rod and no welding flux

weld spatter or slag to remove and the smooth fillet needs no grinding.

Small subassemblies for hospital beds are braze welded. Where stresses are unusually high, a high strength, low fuming, nickel silver brazing alloy is used. A crank handle, Fig. 8, made from a stamping and a machined tube, is braze welded with nickel silver and is ready for finishing.

The fabrication of steel tubing is not limited to furni-

Fig. 12 Tote baskets, carbon-arc braze welded with copper-silicon welding rods, are easily cleaned for galvanizing
There is no slag or weld spatter to remove

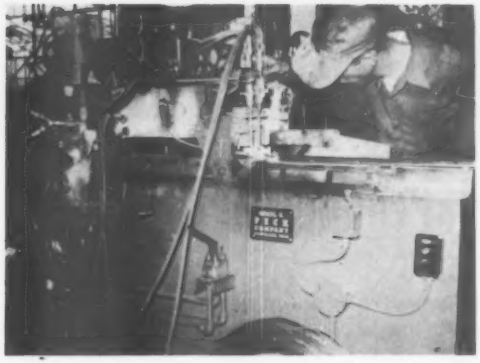

Fig. 13 Braze welding goes automatic

This machine makes two braze welds at once. It is equipped with four oxyacetylene torches, two flame-fluxers and two wire feeders for the coiled low-fuming bronze welding rod.

Carbon-arc braze welding is also used in the fabrication of metal cabinets and other furniture.

Production braze welding is not limited to manual operations. In Fig. 13 we see an automatic machine equipped with four torches, a flame fluxer and a device for feeding the coiled low-fuming bronze welding rod to the joint. Two fillet welds are made simultaneously, at the rate of 15 in. per minute. The fillets are smooth and ready for finishing as they come from the machine.

Braze welding, long referred to as bronze welding, is not new. But these applications of braze welding are comparatively new. Oxyacetylene braze welding with large tips, with low fuming bronze or nickel silver rods and automatic flame-fluxing makes this process adaptable to many new production uses. Dissimilar metals may be braze welded with almost any type of joint and little or no special joint preparation. The deposited metal is sound and strong and the surface is smooth. Except where a flush, butt joint is needed, sanding or grinding is never required.

When all the joining costs are counted, from edge preparation through finishing after welding, braze welding is really economical. Many users report savings up to 50% of the cost of doing it the old way.

The authors wish to thank the Simmons Co.; Sturgis Posture Chair Co.; Karryall Body, Inc. and F. W. Wakefield Co. for their generosity in supplying illustrations.

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PRACTICAL WELDER AND DESIGNER

Stud Welding Speeds Steel Production

Emergency demand for increased steel production means that mills must keep output at highest possible levels. Stud welding, a relatively new method of fastening, has proved extremely useful as a maintenance tool for such steel mill applications as open-hearth doors, wet skid tubes, open-hearth burners and crane rails

by Robert C. Singleton

WITH the entire steel industry exerting every effort to expand capacity in order to meet the accelerated demand of a war emergency imposed on top of extraordinary consumer requirements, any new technique method which results in increased mill capacity or longer operating life for essential equipment assumes greater importance than ever before.

In many cases, the theoretical capacity of an open hearth is limited by the practical necessity of relining the furnace or taking other similar preventative measures.

Perhaps no subject is more controversial among steel operating men than that of open-hearth doors. Not only do individual companies vary widely in their preferences, but divisions and even individuals in a single company have strongly held likes and dislikes. In any case, operating men fully realize the importance of developing the best possible door—one which has a long life, is economical and above all quick and easy to repair and replace.

On all modern open hearths, the doors in front of the furnace consist of a steel frame, an insulated surface which is exposed to the interior of the furnace and a water jacket behind the brick or chrome ore insulating material. In recent years many special doors have been developed in an attempt to obtain the longest possible door life, but all contain these three basic elements.

Recent developments in open-hearth door design which combine the use of plastic chrome ores and end-welded studs have proved that this combination is an excellent one for certain types of open-hearth furnaces.

In one open-hearth mill in the Chicago area a close study of both brick doors and studded and rammed doors has shown that the rammed doors result in cost savings of better than $35,000 over brick doors during a period of one year, and that the eleven furnaces involved are able to increase their production by more than 2500 tons during the same period.

Although all open-hearth doors were originally designed for use with bricks of various sizes and shapes, many mills have swung to a door designed for use with a chrome ore ram mix. Regardless of the type of door being used, end-welded studs have proved an extremely satisfactory means of supporting the ram mix.

This mix is usually a neutral refractory material made of iron and chrome ores with a water glass or sodium silicate binder. When properly rammed and cured, doors made with this material are capable of withstanding more than enough heats to counter the increased initial cost of this type of door when compared to brick doors. Many operators have found that on a strictly cost per door per heat basis, studded and rammed doors are less expensive, and have the added advantage of lowering labor costs and keeping production losses during door changes to a minimum.

The solid back or tank type door is the most commonly used with ram material. The main advantage of this door is the fact that the entire surface is water cooled. The studs which support the ram material are welded directly to the back plate of the door. A variation of this door is the combination panel door, which includes a series of peepholes for determining the condition of the door insulating material from the outside of the furnace.

The true panel type door, originally designed for use with refractory brick, is also adaptable to the studded and rammed construction. Filler plates may be welded into position between the panels to make the door similar in construction to the combination panel door mentioned above.

Three factors are of particular importance in preparing a studded and rammed door. These are:

1. Stud size and spacing.
2. Proper ramming procedure.
3. Correct curing of the ram material.

Robert C. Singleton is Manager, Industrial Sales, Nelson Stud Welding Div., Morton Gregory Corp., Lorain, Ohio.

The end-welded studs used in an open-hearth door serve two important purposes. One is to provide proper support for the chrome ore ram material. The other function is to provide a heat transmission path from the hot surface of the door to the cooling tank behind in order to keep the insulating material as cool as possible.

Selection of the proper stud size and location depends somewhat upon local conditions and individual preferences. However, a few basic principles apply. Generally speaking, 1/2-in. studs are placed on 2 1/2- or 3-in. centers, while 5/8-in. studs are on 3-in. centers, with 3/4-in. studs on 3- or 4-in. centers. In any event, the studs should be located on the door in such a manner as to assure straight lines. When studs are welded to a door for the first time, chalk lines or a simple wood template can be used. When studs are welded on 3- or 4-in. centers, it is advisable to weld additional studs in the center section of the door immediately above the wicket, since this is the area of greatest deterioration.

Fig. 1 Large chunks of the chrome ore ram mix are broken up and forced into the spaces between the studs

Here, the operator is using an air hammer with a shovel blade attachment to pack the mix with uniform density across the door. Careful preparation at this point will eliminate early spalling of the mix

The proper transmission of heat from the face of the door to the cooling tank depends almost entirely on the bond between the stud and the back plate. Here, the automatic features of the stud welding process prove valuable, since each weld joint represents a complete union between the stud and the plate. Extensive tests have shown that a 1/2-in. end-welded stud is equal in heat transfer qualities to a tackwelded 3/4-in. stud.

Many steel producers are using 1/2-in. studs, since only a single welding generator is required. However, others prefer 5/8-in. studs due to the greater heat transfer resulting from the larger section.

Once the studs have been properly end welded in

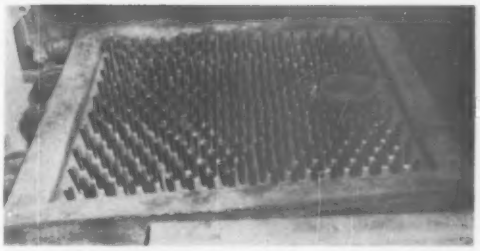


Fig. 2 This view of an open-hearth door after the studs have been end welded in position shows how they should be welded in straight lines across the door surface

Extra studs are often welded in the area immediately above the wicket since this is the point of first deterioration. Spacing between the studs varies with the size being used. The studs serve to support the chrome ore mix and furnish an efficient heat transmission path from the door surface to the water cooling tank

position, the next step is to ram the chrome ore into the space between the studs. Since the length of life of the open-hearth door depends to a great extent upon the condition of the insulating material, it is important to take a few simple precautions in ramming the material into position.

Three major factors should be considered in selecting the ramming method. These are:

1. The material should be rammed in such a way that maximum density is obtained. This will avoid air pockets, hot spots, improve heat transfer qualities and prevent spalling.
2. The insulating material should be free of laminations parallel to the surface of the door to avoid spalling.
3. The door must be cured properly to drive out most of the moisture and thus avoid formation of steam pockets.

The most common ramming method now used is to place large chunks of the ore in the door and then pack it into position by means of iron poles or bars. The chunks should be larger than the thickness of the door to avoid laminations which would be built up if small pieces were used. The main disadvantage of this method is that it is difficult to obtain a uniform high density across the entire surface of the door.

A variation of this method is to use a spade-shaped tool to cut up the chunks of ore. The ore is added in two layers, but the action of the spade results in laminations which are at right angles to the surface of the

Fig. 3 Studded and rammed doors are laid flat while they are being cured to remove excess moisture from the chrome ore mix

Some venting, as shown above, is necessary to speed the drying process and to eliminate potential steam pockets. The doors should remain flat until they are ready to be installed on an open-hearth door

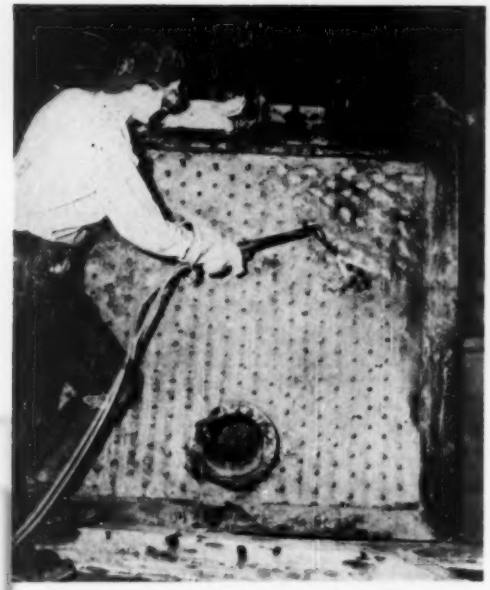


Fig. 4 A scarfing or rivet-cutting torch is then applied to the back plate of the door to burn off the nubs of the end-welded studs

Studs should be welded in the same location each time the door is repaired, and this burning process effectively removes all surface material that might interfere with a good weld joint between the stud and the back plate. Proper preparation of the door before welding is essential to long door life

door, not parallel to it. This method is recommended if hand ramming is used.

An air gun with a round-nosed or blade-like tool can also be used. The same precautions about building up layers of the ore still apply.

After the ramming is completed, the surface of the door should be evened off with a trowel or spade. The ram ore should not extend past the ends of the studs by more than $^1/_8$ in., since this portion will spall off immediately.

The door surface should be left rough. If the surface is slick, it should be roughed up with a wire brush. This item is important, since floating or slicking the surface draws the binder in the mix to the surface, where it forms an impervious crust, and makes drying operations difficult. Of equal importance is the fact that the material below the surface is deprived of the necessary binder, thus increasing chances of early failure.

The doors must be cured before they can be installed, since the ram mixes contain an excessive amount of moisture to assist in working the material. The most common curing method is to circulate steam through

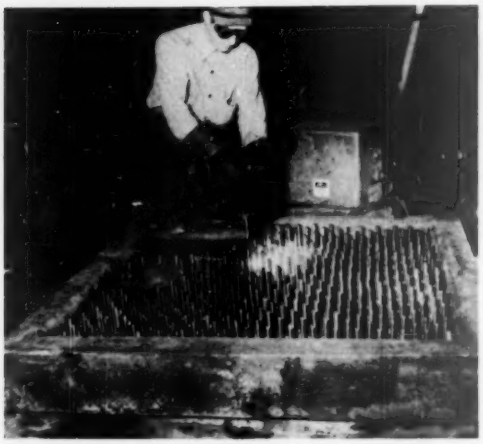


Fig. 5 Studs are end welded to the back plate of the open-hearth door by the Nelson portable stud-welding gun

The studs are welded in straight rows to facilitate ramming the chrome ore into the door. Consistent positioning of the studs is assured when new studs are welded in the location of the previous ones. However, the nubs of the old studs must be cleared away each time

the water cooling tank of the door. While being cured, doors should be in a horizontal position, and should remain that way until ready for use.

After a door has been removed from an open-hearth furnace for relining, it is important that it be prepared properly. The first job is to remove the slag and remaining ram material with an air gun or chipping hammer. Then, all of the studs should be removed by a scarfing or rivet cutting torch and the interior surface of the door swept out.

Complete removal of all of the old studs is particularly important to the proper operation of the door. One reason is that the new studs should be end welded to the back plate in the same position as the old ones. This prevents a build up of old ram material, makes packing easy and lengthens the life of the door. Another reason that the new studs should be welded in the same position each time is that perfect welds are obtained, since the burning action of the torch removes all old metal and ram material from the welding area. This item is of considerable importance, since one of the major functions of the studs is to carry heat away from the surface of the door to the cooling tank, and a solid union between the stud and the back plate is essential. Unless the nubs of studs are removed each time a door is changed, the entire surface of the door will become covered with a layer, consisting of nubbins, chrome ore and slag, which forms a barrier that reduces the cooling effect of the water.

Welding on the Farm

AN easily constructed 20-ton hydraulic press is shown in Fig. 1. This adjustable height press has many uses around the small shop or farm. The unit is fabricated from I-beam and channel steel stock. Steel rods placed through holes in the channel upright allow up and down adjustment of the base platform. A hydraulic jack inserted between two sheets of plate steel furnishes the pushing force for the unit. Two steel bars attach to the lower piece of sheet steel and pass through the upper plate and on above the press. Above the press two coil steel springs enclose the bars and exert an upward pressure to the lower plate when the air on the hydraulic jack is released. This action frees the work in the press. Here the press is being used for replacing bushings in a tractor track roller.

Photographs and data, Courtesy The Lincoln Electric Co., Cleveland, Ohio.

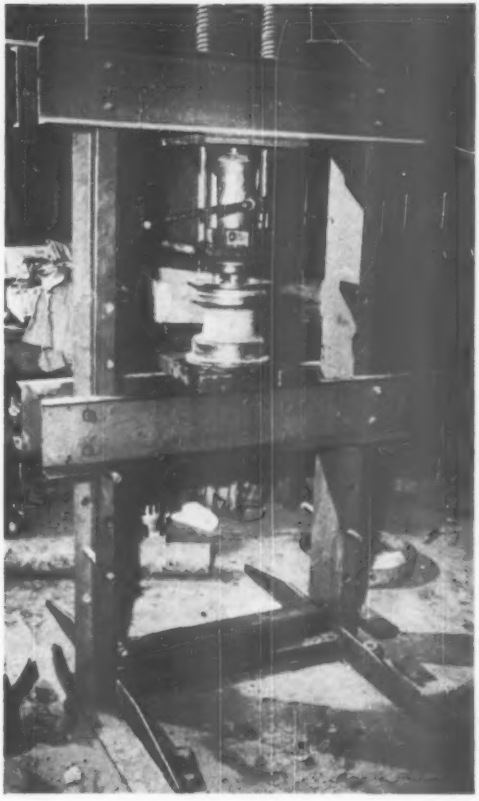


Figure 1

Figure 2

Figure 3

Why work standing up when you can do a better job sitting down? M. P. Shores, Jr., Barnett, Mo., answered that question by welding knee-action coil springs to old brake drums and topping it off by welding on a comfortable cultivator seat (Fig. 2). He finds them useful in painting trailers which he makes. Now he has made several, using different springs and different heights so that he has the right spring seat for the job.

Welding jig and clamp made by Shores consists of a base made from an auto axle housing (Fig. 3). The vertical pipe is adjustable for height and may be set in any position by tightening a wing nut. The clamp, or horizontal part of the device, rotates in a bearing at the top of the vertical section. The top part of the horizontal part is hinged to the lower member like a pair of scissors or pliers and the jaws are held shut for tension on the work by a coil spring.

In use the clamp is quickly attached to work to be welded and may then be rotated in either direction, or raised up and down, all directed toward quick and easy positioning of the work.

Welded Bridges

by Dr. Alois Cibulka

WE MUST streamline our bridges as well as our thinking. First of all we must diversify the materials, use each in its proper place to get the full benefit of its natural qualities.

Competition between materials and labor working them will also help to a large extent.

Dr. Alois Cibulka is connected with the Engineering Dept., The University of Houston, Houston 4, Tex.

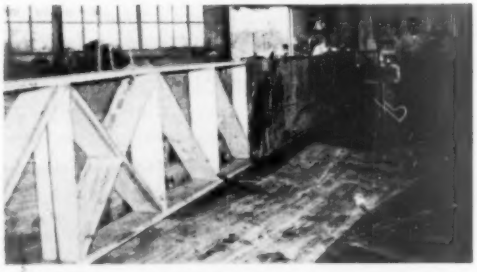


Fig. 1 "RST" beam in fabrication 12 in. x 48 in. x 65 ft. long

Saved 210 lb. per lineal foot or 13,500 lb. of steel per beam against rolled I which was not obtainable at that length without welding. Cost of timber for core was $25.00. Delivered to the welding shop the core cost was $75.00. Cost of extra steel would have been $675

36-In. WF rolled beam of same capacity had too much deflection and would have to be reinforced with cover plates

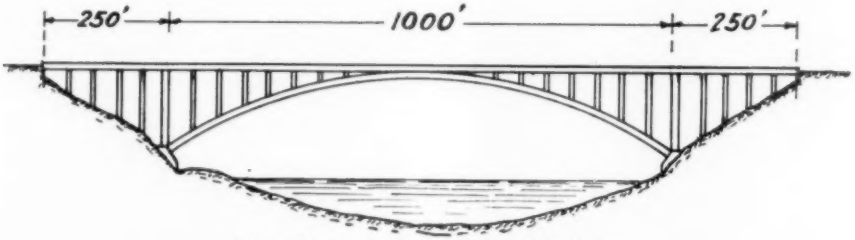


Fig. 2 Most economical bridges of the future

Aluminum arches and columns with timber cores sealed by welding. Super structure: beams and girders enclosed in steel by welding. Precast concrete decks with asphalt top. Example: 1500-ft. long bridge with 1000-ft. central span; 56 ft. wide; 4 lanes; 2 sidewalks

For comparison used: George Westinghouse Bridge in Pittsburgh built in 1932 of concrete. This four-lane bridge is 1524 ft. long, 56 ft. wide with two 7-ft. sidewalks; its central arch of 418 ft. is the largest of that type in America: total cost $3,606,000; $2360 per lineal foot

Estimated cost of above bridge:

Items	*Steel, lb.*	*Aluminum, lb.*	*Timber, fbm*	*Cost*
Railings, curbs, asphalt	...	...	...	$ 27,500
1350—5-ft. x 10-ft. precast panels	...	...	...	67,500
151—1-ft. x 4-ft. x 48-ft. beams	1,250,000	...	115,000	130,000
2—4-ft. x 6-ft. x 1500-ft. girders	700,000	...	125,000	82,000
4-ft. x 4-ft. columns and braces	...	160,000	180,000	75,000
2—4-ft. x 12-ft. arches	...	750,000	1,000,000	490,000
Totals above	1,950,000	910,000	1,420,000	$ 872,000
Foundations, erection, engineering, contingency, contractor				628,000
TOTAL COST				$1,500,000
Per lineal foot $1000				

Assumed material costs:

Steel as fabricated: 9 cents per pound

Aluminum as fabricated: 32 cents per pound

Timber for superstructure, rough, green, nailed cores: $150 per 1000 fbm.

Timber for arches: rough, dry, glued and nailed: $200 per M. Precast 5-ft. x 10-ft. deck panels: $50 each

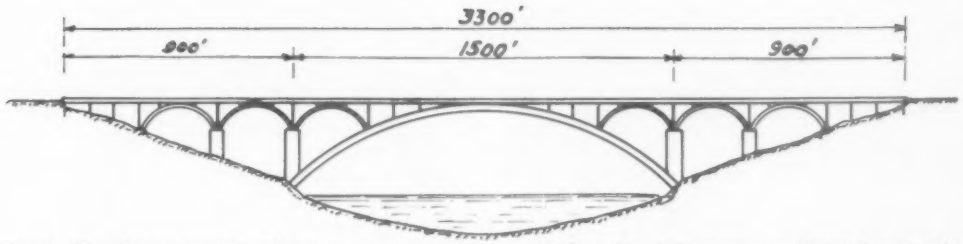


Fig. 3 All arches are erected without any centering. They can be floated in shallow water and hoisted on piers by means of short Gin Poles

All Arches are erected without any Centering.

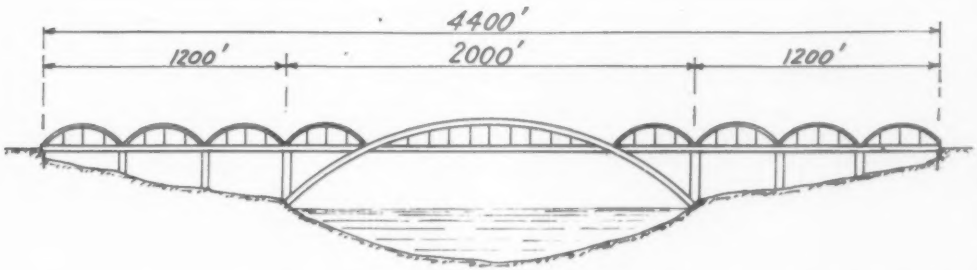


Figure 4

The dead weight of these bridges (Figs. 3 and 4) is about 10% of similar reinforced concrete structures. Timber cores are the best shock absorbers obtainable. Lightness plus resilience make these bridges supreme for earthquake regions. Cost less than one-half of prewar bridges. Very low maintenance cost

All bridge parts should be shop fabricated under good control so that higher stresses will be allowed, thus lowering the cost without impairing the safety of the structures.

The bridges should be prefabricated while the foundations are prepared and erected by riggers, each part capable of taking the full load as soon as placed. Time for construction could be easily reduced to one-half or less.

Painting should be reduced to the minimum or entirely eliminated for those parts that are not easily accessible like arches and columns. Surfaces should be smooth and streamlined.

Cement manufacturers are very active in advertising the concrete bridges and in the past the concrete structures were my favorites all around. But since the welding process developed to such a perfection I just cannot understand that any engineer can waste the time and money on reinforced concrete structures above the ground level or on riveted jobs.

It may be a good idea to follow the cement people and push the welding by vigorous advertising of a similar nature. Welding can offer much more to the engineers than any other method possibly can do, and it costs the country billions of dollars in waste that could be easily prevented if the engineers were properly informed.

Clear spans, no bracing of any kind make a beautiful job.

Figure 1 is a good example of what savings can be had even on a comparatively small job as this in Crosby, Tex., where only 4 beams were required. Columns for this job made in a similar way saved another $1000.

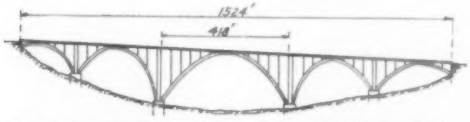


Fig. 5 George Westinghouse Concrete Bridge in Pittsburgh. Cost per lineal foot: $2360 in 1932

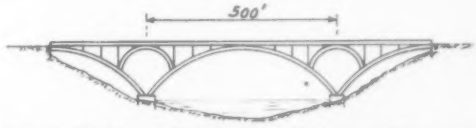


Fig. 6 Modern welded bridge. Typical rainbow arc. Cost per lineal foot less than $1000 in 1950

Automatic Welding for the Transcontinental Hudson River Crossing

THE 26-in. diameter somastic-coated pipe used for the Hudson River Crossing of the Transcontinental Gas Pipe Line has a wall thickness of $1^1/_8$ in. The Omaha Dredge and Drydock Co. in preparing this pipe for the crossing laid at Edgewater, N. J., welded together sections 440 ft. long using an automatic hidden-arc welding process. The 22 joints making up one section were welded in a rig mounting a standard Lincoln Electric automatic head powered by gasoline engine generators. The rig was engineered and developed by the Big Three Welding Equipment Co. of Houston, Texas, working with Crutcher-Rolf-Cummings, pipe line distributors of Houston.

Photos and data courtesy The Lincoln Electric Co., Cleveland, Ohio.

Fig. 1 Stringer passes being made prior to automatic welding of joints in the 26 in. diameter somastic-coated pipe for the Hudson River crossing of the Transcontinental Gas Pipe Line

The pipe, as-received on the job, was first hand welded into sections of two or three joints. A side boom tractor was used for positioning pipe, which was lined up with both internal and external line-up clamps. The pipe came with a $^1/_8$-in. land and a bevel of approximately 35°. Fit-up was held as close as possible to an opening of $^1/_8$ in., but considerable variation was encountered.

The first stringer pass was made with $^5/_{32}$- or $^3/_{16}$-in. E6010 electrode, depending on the fit-up of the joint. A second and third hot pass were also made with the same electrodes.

The sections of two or three pipe were then moved by the side boom tractor to the automatic welding setup. Pipe was laid on rollers mounted on railroad wheels which could be moved up and down a track so that more sections could be added on to complete the 440-ft. section. The entire section was rotated by a turning machine located at one end of the section and which moved down the track as the section lengthened.

Fig. 2 Setup for welding 440-ft. sections of pipe

Complete section mounted on rollers and track is rotated by machine at far end. Six passes are made to complete the joint. Automatic "Lincolnweld" head is mounted in rig at near end of section.

Fig. 3 Close-up view of welding rig

Each pass was cleaned with air chipper and wire brush before making the next. Flux was picked and sifted manually for reuse

Fig. 4 All welds were inspected visually and by X-ray

The joints were completed by making six automatic passes with the hidden-arc process. They were made at a speed of $3\frac{1}{2}$ min. for one revolution of the 26-in. diameter pipe. A $\frac{7}{32}$-in. diameter high-tensile welding wire electrode was used with current on the different passes as follows: 1—450 amp., 2—650 amp., 3 and 4—775 amp., 5—700 amp. and 6—600 amp. Voltage ranged between 33 and 35 v. A chipping hammer and wire brush were used to clean slag from each pass before the next one was made. Welding current was supplied by two 400-amp. gasoline engine driven welders. Flux was manually sifted for reuse.

If the automatic welding was not done immediately following a hot stringer pass, it was found necessary to use a torch to apply a slight preheat to the joint. For satisfactory results it was found best to have a preheat temperature, in the area to be automatically welded, of 250 to 300° F. All welds were inspected visually and with X-ray.

On the average six complete automatic welds were finished in one day. Approximately 12 lb. of metal went into each joint, or approximately six joints were obtained from each roll of electrode wire.

A Potter's Wheel for the Welder

DESIGNED on the principle of a potter's wheel, this bench has a built-in turntable to facilitate welding, brazing or soldering operations. The operator, sitting at the bench, places the work on the turntable and turns the flywheel with his foot to position the work.

Although this type of bench can be made any size, depending on the work, the following dimensions are generally the best. The turntable is $\frac{1}{2}$-in. thick steel plate approximately 14 in. in diameter and is welded centrally on a $\frac{3}{4}$-in. shaft. Suitable bearings are provided to permit smooth running consistent with the type of work to be done. There are a number of bearing arrangements which may be used. However, at least one of the bearings will have to take the vertical thrust resulting from the weight of the turntable unit and the work. Also, at least one of the bearings will have to take radial loading.

Welded 3 in. from the bottom of the shaft is the flywheel which weighs at least 20 lb. and is 15 in. in diameter. Weight of the flywheel should be enough to ensure a smooth-running turntable. It may be made from a steel plate or from an old machine flywheel.

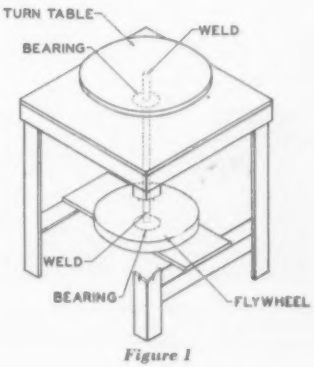
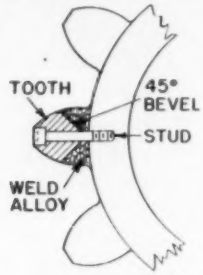


Figure 1

Welding Broken Gear Teeth

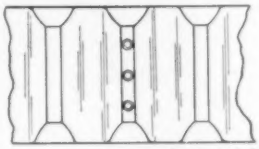
IF a gear tooth, in which the close meshing of the teeth is not a primary consideration, breaks, it may be replaced after beveling the underside, by studding it in place and building up the underside with a suitable welding alloy. As this may be done with the gear attached to the machine, it will save the expense of removing the gear from the machine and cut the downtime.

The tooth of the gear is first beveled on the underside at a 45° angle so that when the bevel is completed, the roots of the bevel will expose the studs that are used to hold the tooth in place, Fig. 1. Then the studs are put in the tooth and the tooth studded firmly in place. With the tooth in position, select an appropriate welding rod and lay in the welding alloy using the backstep method. Continue to build up the weld until all the space between the outer edge of the bevel and the rim is filled. When the weld is finished, use a grinder to remove the rough spots and reshape the tooth.



Courtesy Air Reduction Sales Co.

Fig. 1 Method of repairing broken gear tooth



Courtesy Air Reduction Sales Co.

Fig. 2 Completed repair of tooth showing use of studs

Repairing a Jeep Windshield Frame

by R. K. Hughes

METAL furniture and tubular handles for shop and farm equipment sometimes give you troublesome repair problems. You will find that it is easy to make a strong, permanent repair if you use a reinforcing liner. Here is how to make a fast, easy repair on a tubular part like a jeep windshield frame. Use the same method for other tubular parts.

First, remove all dirt, rust, paint and scale for about 1 in. back from the broken edges. Then cut back 1/16 in. or so on each side of the break but leave 3 or 4 equally spaced sections unchanged. Make these sections about 1/8 in. long. These sections will, when butted together, position the parts so they line up correctly in their original dimensions. An open gap will result between the tightly positioned sections making it possible to get bronze weld metal onto the liner as the weld is made.

Cut a length of tubing or pipe for the reinforcement. It is best if there are about 3 or 4 in. of the reinforcing liner on each side of the break. In the case of this windshield frame, the curve of the part makes it impossible to have more than 1 1/2 in. of the liner on each side of the break. The liner should fit snugly into the frame tubing so that you have to tap it into place.

R. K. Hughes, Oklahoma City, Okla.

Fig. 1 This shows the broken windshield frame after the edges have been prepared and the reinforcing liner put in place

Fig. 2 Use a slightly oxidizing flame and bronze welding rod

Start tinning when the heated edges turn a medium red

Fig. 3 A piece of asbestos paper will help keep the heat off the body of the jeep

Insert the liner in one side of the frame. Make a very small tack-weld at one of the cut back spaces to keep it in place. Then set the liner in the other end of the broken frame.

It is best to do this job by braze welding (also called bronze welding) because you need only a low heat and can work quickly. Hold the flame about $^3/_4$ to 1 in. away from the work and heat the metal along the break. Make sure the reinforcing liner is heated to bronze-welding temperature at the weld region, too. Start to tin the broken edges and the exposed liner surface with bronze welding rod when the metal turns a medium red. Be sure to use bronze welding flux on the rod, too. Weld all the way around the frame and be sure to get the molten rod welded to the inner reinforcing liner. When you finish, the weld metal should be slightly higher than the surface of the tubing. If it isn't high enough on the first pass, put on another layer of welding rod. But be sure to remelt the first layer as you add more weld metal.

Clean the flux from the weld area with a file or wire brush and then repaint the repaired part.

Hints for Cutting Thick Steel

by O. J. Swan

WHEN you first try to cut thick steel the important thing to remember is to use the oxygen pressure recommended by the manufacturer of our blowpipe. Many operators make the mistake of increasing the oxygen pressure because the material is thicker than they usually cut. But this will give you lots of trouble. High pressures cause distortion of the cut. Frequently, an increase in pressure will form a cavity which prevents the cut from progressing to the desired depth.

Cutting with an oxyacetylene blowpipe depends only upon the reaction between oxygen and the red-hot iron or steel. All you need is enough oxygen to keep the reaction going. Excess pressure will interfere with the cutting action just as too much draft will blow out a fire. Here are some hints that will help you do a better job.

CUTTING STRAIGHT LINES

Figure 2 (*A*) shows what may happen on some of your straight-line cutting jobs. A

O. J. Swan, The Linde Air Products Co., Chicago 1, Ill.

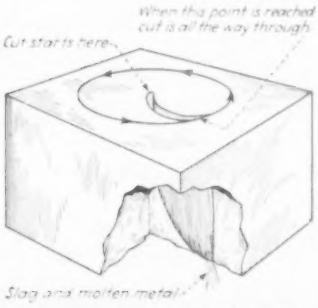


Fig. 1 When you reach the line of cut, the cutting-oxygen lever should be depressed all the way

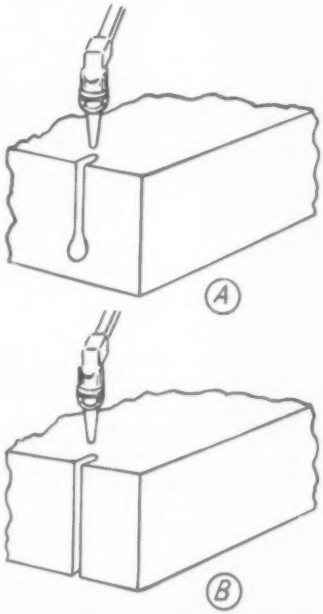


Fig. 2 To prevent pockets, get the cut started through the entire face before you press down the cutting-oxygen lever all the way

pocket has been formed and further downward penetration will stop. Here is how to avoid it. Preheat the edge of the metal with the tip of the preheat flame, about $^1/_{16}$ in. above the surface, until the line of cut for the full thickness has been heated to a bright red. Then back away from the work $^1/_4$ to $^3/_8$ in. Press down the cutting-oxygen lever slightly, and with the nozzle at a slightly trailing angle, lead into the cut slowly. Straighten up the nozzle as the cut reaches the bottom. Do not press down the cutting-oxygen lever all the way until the cut has traveled through the entire face as shown in Fig. 2 (*B*).

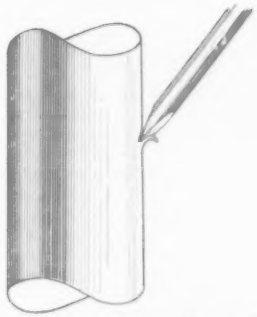


Fig. 3 A lever on a round bar or shaft lets you get a quick start

Mark the outline of the hole with chalk and a center punch. Start the cut in the part of the metal you will discard; in the case in Fig. 1 it is the center. Hold the blowpipe so the ends of the preheat flames are about $^1/_8$ in. above the surface. Heat the metal at this point until it almost melts, then gradually press down the cutting-oxygen lever. At the same time move the blowpipe, with the nozzle perpendicular to the surface, toward the chalk line. Regulate the speed with which you depress the cutting-oxygen lever and the speed of nozzle movement. In this way when you reach the starting point of the intended line of cut you will have pierced the entire thickness. By that time the cutting valve also should be depressed all the way.

CUTTING ROUNDS

To start a cut on a round bar or shaft where there is no corner—first make a deep nick with a chisel and a hammer or sledge. The tip end of the sliver of metal will become red hot almost the minute the preheating flames touch it. This will allow you to get a quick start.

Tapers for Resistance Welding Electrodes and Holders

A new improved standard taper for resistance welding electrodes has been developed which has a number of advantages

by W. E. Smith

ABSTRACT

THE USE of resistance welding as a production tool for spot and projection welding, required, due to rapid deterioration under production conditions, the use of electrode tips that could be replaced in holders with a minimum of down time. Of the several types of joints, the one generally accepted was the Morse Standard, probably because it was an established taper as used on machine tools and its holding power was known. However, welding presented problems not encountered in other applications and a subcommittee was appointed by the A.W.S. Automotive Welding Committee to study and suggest improvements.

PROBLEMS

The Morse taper is a self holding or locking taper offering a high degree of resistance to its removal and good contact friction for driving, which is desirable for drills, arbors, etc., as used on machine tools. However, to consider the problems when used on welding machines:

1. Materials for electrode tips and holders are copper or copper alloys for maximum electrical conductivity.
2. Continuous hammering of tip into holder with varying impact forces makes removal difficult.
3. Water used as coolant requires a tight joint to prevent leakage.
4. Frequent removal of tips causes scoring of contact surfaces and distortion.

STUDY

Analysis indicated that a joint requiring less energy to remove would minimize these difficulties, also that the problem

W. E. Smith is Welding and Electrical Engineer, Midland Steel Products Co., Detroit, Mich.

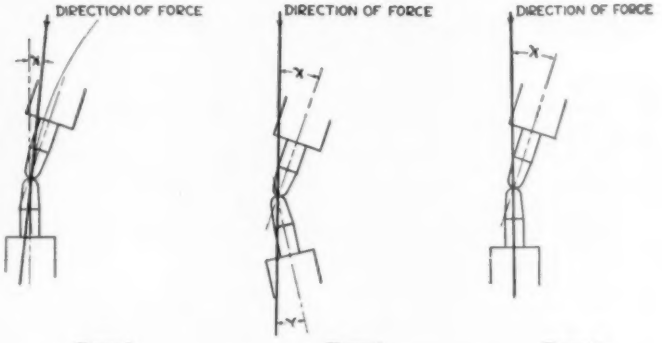


Figure 1 Figure 2 Figure 3

Fig. 1 The maximum angle of position recommended for use with experimental taper tips to be determined by the following formula: x = 40 over-all length of tip. X is the angle in degrees between the center line of the tip and the direction of force

Fig. 2 The direction of force on rocker type guns is parallel to the line tangent to the arc generated by the movable tip at the point of contact between tips

Fig. 3 "X" or "Y", whichever is greater, shall be used to determine the maximum angle recommended for using experimental taper tip

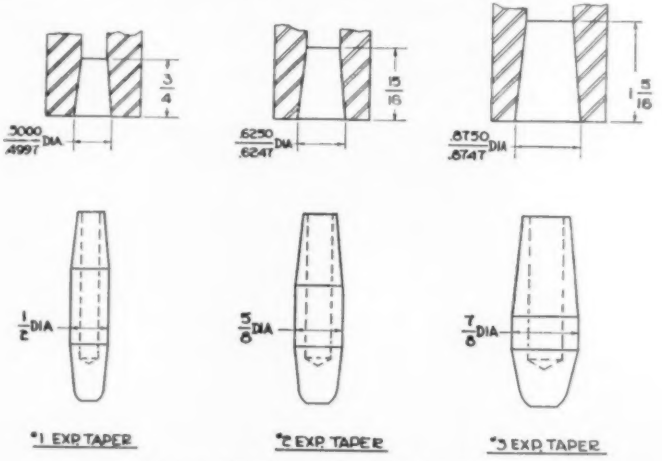


Fig. 4 Experimental taper for electrodes

3° 57′ 45″ included angle = 1.25 in. per foot. Taper length = 1.5 x major tip diameter

has been recognized and attempts made to correct same with tapers to 15° as well as both straight and pipe threads with varying degrees of success.

This subcommittee arrived at a taper of 6° as having good holding power and being less difficult to remove. This taper was later corrected to 1¼ in. per foot or 5°, 57′ 45″ included angle at the request of the manufacturers (R.W.M.A.) as being less difficult to produce with no difference found in use. Figure 4 shows accepted design for tips and holders.

Off-center loading of tips, such as encountered on gun or portable welders, presented some difficulty when the angle of loading was greater than 30° from vertical. It was found that if bumping occurred while the welder was being moved it was possible for the tip to loosen and fall from the holder. This condition was improved by increasing the length of taper. Figures 1–3 show method of calculating recommended maximum angle and tip length.

A series of holders and tips were furnished and set up on production in several plants with the following results reported:

1. Increased life of tip and holder.
2. More consistent welding due to contact surfaces being maintained.
3. No difficulty with water leakage or scoring.
4. Tips did not freeze; required less effort to remove.

Actual tests (direct pull on Olsen testing machine) indicated 30% less energy required to remove:

Vertical setup, No. 2 taper only, average of six specimens each test:

Morse No. 2	12,730 lb.
1¼ in. per foot	9,890 lb.

Thirty degrees off vertical, No. 2 taper only, average six specimens each test:

Morse No. 2	14,160 lb.
1¼ in. per foot	10,125 lb.

CONCLUSION

Although the new 1¼-in.-per-foot taper has been found to be an improvement over the Morse taper for welding operations and is at present used in several plants with very satisfactory results, the problem of changing over must be considered. A plant using several hundred units should meet the cost of a complete changeover of parts at one time to eliminate the possibility of confusion with more than one design.

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AMERICAN WELDING SOCIETY
33 West 39th Street, New York 18, N. Y.

President's Address

Presented at Annual Business Meeting

By O. B. J. Fraser

The thirty-first year of the SOCIETY's existence, now drawing to its close, has been marked by important progress in some respects and by unfortunately retarded activity in others. Details of the year's operations are given in the reports of our officers and the Chairmen of our Standing Committees.

The financial problem we have had, in common with most other professional and technical societies, was not solved during the year. Despite careful budgeting, our operations have resulted again in a deficit of some magnitude because of continuing increases, amounting to about 5% overall, in operating costs with only a modest increase of about 10% in income from dues and other sources.

Membership, despite great effort on the part of the Membership Committee and the Headquarters staff, is substantially unchanged from that at the year's beginning, whereas a sizable increase had been expected and allowed for in our budget. The even figure was maintained largely by opening new sections; very few of the older sections have shown notable increases. The number of members dropping out for one reason or another has kept pace with the number of incoming new members. In other words, good progress has been made in opening up new areas, but membership growth has been retarded, on balance, in the previously established areas. Toward improving this situation the by-law on committees was revised to provide for installing the new membership committee in June of each year; so that its plans can be made and implementation begun in September of each year rather than on toward the end of the first quarter of the SOCIETY's membership year. The Membership Committee's current plan of action is well conceived, the competitive angle between intra section teams that is being introduced has worked in sections where it has been tried, and the added stimulus of intersection competition should be equally productive. It is not possible for me to overemphasize the importance of full cooperation from the entire membership in promoting the enlistment of new members. Dues brought in about 47% of our total income this year. If we who are now members are to reap the maximum benefit from membership services we must build up our membership income to a much higher level than we now receive.

Our monthly publication, THE WELDING JOURNAL, brought in about 31% of our income, exclusive of the portions of dues allotted to Members' subscriptions. It also accounted for about 36% of our expenses. The JOURNAL in former years was a producer of considerable net income, but rapidly rising costs of paper and printing have reversed that previously satisfactory situation. A drop in yield from advertising, an experience which has been the common lot of such publications as ours and also of commercial technical magazines, has aggravated the situation. Steps have been taken to improve matters, by devoting a good share of the National Secretary's time to solicitation of advertising and by substantially increasing advertising rates, to bring them back into line with those of other magazines.

Another large item of expense is the rental charge for headquarters office space, which also was increased during the year. A special committee was appointed to study this phase of the SOCIETY's operations.

Our Technical Activities, after having been under wraps for three years or more while the Technical Staff at headquarters was engaged in bringing out the new Third Edition of the *Welding Handbook*, have been resumed, but not on the scale that their importance to our entire membership warrants. It has been necessary as one means of reducing the unfavorable gap between income and outgo, to dispense with the office of Assistant Technical Secretary which means that the desired volume of technical activity cannot be attained. Means of overcoming this condition are being given earnest study and it is hoped that very soon a way of financing adequate headquarters staff will be forthcoming. This part of our service to industry and ourselves is of paramount importance to us all and no effort will be spared to bring it into full operation.

In cooperation with the Welding Research Council our SOCIETY has continued its membership in the International Institute of Welding. The scope of this organization's work is still in process of development so it is not yet possible to formulate a firm opinion of the technical value to our membership. As a measure of goodwill and evidence of a cooperative spirit in international affairs it seems to be very much worth while at this time for us to continue membership.

Consideration, at some length, was given to the educational aims of the SOCIETY, not only by the Educational Committee, in the regular course of its operations, but by the Executive Committee and the Board of Directors. The latter groups

Charles H. Jennings Receives 1950 Adams Lecture Award

President Fraser Presents the Miller Memorial Medal for 1949 to Wendell F. Hess

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MACHINE BUILDER CUTS DEFLECTION 80%

BASIC objectives of increased rigidity and greater machine accuracy are today being achieved at lower cost with welded steel designs. As illustrated in the redesign of the Facing Planer for the Porter Machinery Company, the present welded steel table when supported on three corners indicates a deflection of only .014" where as the former cast construction sagged as much as .070". Simultaneously, a reduction in weight from 410 lbs. to 320 lbs., made possible by the increased stiffness of welded steel, enables a tolerance of .001" to be maintained on surface flatness.

How to Steel Design With Welding is presented in the new 9th Edition "Procedure Handbook of Arc Welding Design and Practice." Contains latest data on machine design together with cost figures. Price only $2.00 postpaid in U.S.A.; $2.50 elsewhere.

Left: Checking table deflection at Porter Machinery Company, Grand Rapids, Michigan. Center: Unsupported corner of former 36" planer top sags .070". Right: Present welded steel table deflects only .014".

the **ACTUAL**

Former Design. *Had heavy base serving no other purpose than to unify planer.*

increasing the **YIELD**

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dealt with a proposal from an outside source that the SOCIETY support a correspondence course in welding engineering along lines that have been followed successfully in Canada during the past two years.

It has been my privilege, during my term of office, to visit and confer, at individual section meetings or at group conferences, with the officers, and in some cases the membership, of twenty-five of our sections, scattered over all but one of our seven districts. I am grateful indeed for the cordiality shown me on every occasion. It was a stimulating experience to me in discharging my Presidential duties, and, I trust, may have been of some benefit to the sections, especially those where operations have been difficult for one reason or another.

My year as President has been one of problems and of pleasure. The privilege of serving is an honor that I shall cherish always, but always with the memory, which I acknowledge with gratitude, of the contemporary services of others. The National Secretary, the Assistant Secretary, the Editor of THE WELDING JOURNAL, the Technical Secretary and the other members of headquarters staff have been faithful and unstinting in their efforts. The members of the Board of Directors and the Executive Committee have been diligent in the discharge of their duties, and so also have the Section Officers throughout the country. To them and to the Chairmen and members of our various standing, special and technical committees, I extend my thanks for their loyalty and their services to the SOCIETY. Special commendation is due to the Chairmen and members of the Handbook Committee and its editorial staff for the splendid results of their efforts in the new edition of the *Handbook*.

For our incoming President, H. W Pierce, and his fellow officers and Board members I ask your continued support. Mr. Pierce's long experience, as a member of the Board, with the management of the SOCIETY and as a member and past-chairman of the Technical Activities Committee, with its technical interests, assure us that we can look forward to a successful and satisfying year.

Preface to Secretary's Report on Activities of the American Welding Society for Administrative Year Ending Aug. 31, 1950

(Presented at Annual Meeting)

Briefly, but with emphasis, I will treat only with the most vital items covered in my complete report, of which a copy will be mailed to any member upon his request. It includes a summary of our Standing Committee's activities reports.

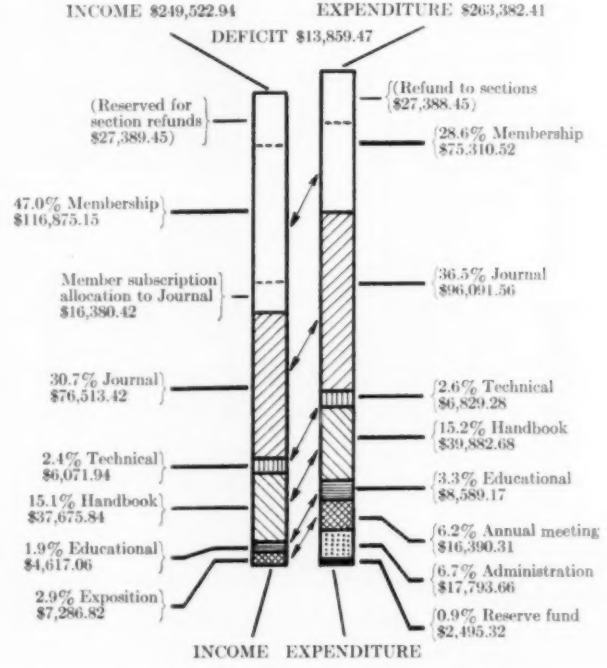
Our President has touched upon each of our problems. I wish to emphasize the vital details regarding income, expenses and membership, as well as, very emphatically, state our immediate requirement.

If our SOCIETY is to grow and serve Industry in the manner Industry very evidently desires, both Members and Industry must join with us in evolving and supporting a pattern which will place the AMERICAN WELDING SOCIETY upon a firmer footing than that now held; one which will relieve us of the continued strain to satisfy our day-to-day requirements; a pattern which will provide us an income excess over existence expenditures; an excess that can be utilized for supplying additional necessary Member and Industry services.

We reduced our headquarters' staff in numbers, our headquarters' space, our Section activities, the page content of our WELDING JOURNAL and our travel program in direct proportion to our anticipated income for the past year. But increases in all operating expenses, such as printing and paper costs, headquarters' square footage rental, employee salaries to maintain a fair ratio with industry scales, miscellaneous services, replacement of worn-out equipment, combined with a reduction in WELDING JOURNAL advertising, books and publications sales and membership, resulted in a deficit for the year of $13,859.47. In the previous year we received $57,569.99 advertising income. In 1949–50 that income was reduced to $47,734.77; a loss of $9,835.22; or greater than a 17% drop.

During 1949–50, 47.0% of the SOCIETY's income was derived from Membership; 30.7% from THE WELDING JOURNAL; 2.4% from Technical Releases; 15.1% from the *Welding Handbook;* 1.9% from Educational Books and 2.9% from National Welding Exposition receipts. Our income was $249,522.94.

In the same period our operating expenses were $263,382.41; approximately 5½% more than our income. 28.6% was spent on Membership; 36.5% on THE WELDING JOURNAL; 2.6% on Technical Activities; 15.2% on the *Welding Handbook;* 3.3% on Education; 6.2% on the Annual Meeting; 6.7% on General Ad-



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During 1949–50 our national membership loss was 59 members, our registration dropping from 7191 to 7132. Thirty-four sections lost 400 members. Twenty-two sections gained 173 members. We opened 5 new sections, gaining approximately 200 members. But it is not possible to balance the losses mainly contributed by our older and larger sections by opening new sections in the few remaining open areas of small industrial activity. In the 20 major U. S. industrial cities, at their individual membership peak years, those 20 Sections totaled 5564 members. As of June 30, 1950, those 20 major Sections totaled but 4082 members; a loss of better than 26.6%!

Every activity of our SOCIETY benefits every individual member, as well as every industrial organization using welding or welded products. Based upon an expenditure of $263,382.41 and 7132 registered members, we are returning each member $36.93 worth of service for which the "average" member pays but $16.27. He gains 127% on his investment; a tremendously higher rate of gain than he obtains from any one, if not all, of his other investments or expenditures.

Metals fabrication production and sales, as well as personal income, are higher today than they have ever been. Consequently, there is no tenable reason for those interested in welding engineering, 15,000 individuals at least, and all industry engaged in welding activities not supporting this SOCIETY. It is obvious that membership, being our No. 1 source of income, must be increased. Additional membership will provide additional WELDING JOURNAL circulation. Additional JOURNAL circulation will raise its value to advertisers. Additional advertising income will automatically result.

As your Secretary, I can but urge that every National and Section Officer and every member make our membership problem his problem during this coming year, and can but suggest that if all industry engaged in welding or interested in welded products desires that the AMERICAN WELDING SOCIETY continue and expand its good work, then it must early collaborate with and adequately support our SOCIETY in its National and Sectional activities to a far greater extent in the immediate future than has been the custom in the past.

Representing our National Headquarters' Staff, I extend our Staff's and my real appreciation to President Fraser for his ever-available administrative direction and invaluable advice, and to our National and Section Officers for their voluntary and highly valued assistance during the past year. We look forward with pleasure to our working with our incoming President, H. W. Pierce, and our present and new National and Section Officers. We appreciate the loyalty and voluntary assistance and support of all of our Members and know that all of you join us in hoping that the 1950–51 SOCIETY year will be one blessed with solutions to many, if not all, of our SOCIETY's problems.

Sincerely and appreciatively,
J. G. MAGRATH, *Secretary*

Jennings Gives 1950 Adams Lecture

Mr. Charles H. Jennings, on nomination of the Committee on Awards, was selected by the Board of Directors to give the 1950 Adams Lecture. Mr. Jennings chose as the title of his lecture, "Dynamic Characteristics of D.-C. Welding Machines." There follows a brief biography.

Charles H. Jennings was born in Des Moines, Iowa, and attended Iowa State College at Ames, where he received the Degree of Bachelor of Science in Mechanical Engineering in 1928.

Mr. Jennings was admitted to the Graduate Student Course of the Westinghouse Electric Corp. in 1928, and completed the normal year's course in seven months.

Charles H. Jennings

In 1929 he became attached to the Mechanics Division of the Westinghouse Research Laboratories in East Pittsburgh, where he instituted advanced studies in the mechanical properties of welds, welding design, welding applications and welding problems.

In 1936 he was transferred to the Laboratories' Chemical and Metallurgical Dept. and put in charge of all the welding research. In 1943 he was made Section Engineer of the Welding Section and in 1945 promoted to Engineering Manager of the Welding Department which position he now holds.

In 1937, Mr. Jennings was called to England for three months as consultant welding engineer for the English Electric Co. He has also conducted a course in welding metallurgy at the Carnegie Institute of Technology, prepared a training course for welding operators for the Pittsburgh Board of Education and served as part-time staff member of the N.D.R.C. War Metallurgy Division during 1942. He is the author of more than thirty articles on welding and two books, ***How to Weld 29 Metals*** and ***50 Lessons in Arc Welding***.

In 1939, Mr. Jennings was awarded the Westinghouse Silver "W" and Order of Merit for distinguished service in welding research and application. Mr. Jennings has been active in the AMERICAN WELDING SOCIETY for the past twenty years and has held the offices of Chairman Pittsburgh Section, District Vice-President, Director at large and Director Niagara Frontier Section. He was Chairman of the Technical Activities Committee and a member of seven other committees. He has served on six other committees, assisted in the preparation of several chapters for the 1938 and 1942 editions of the ***Welding Handbook***, served as a member of the 1950 Handbook Committee and lectured before thirty-eight sections of the SOCIETY. He is now 1st Vice-President of the SOCIETY.

PRESIDENT-ELECT'S ACCEPTANCE OF OFFICE

By H. W. Pierce

I deeply appreciate the honor you have paid me, and the brevity of my remarks is not to be interpreted as unwillingness to acknowledge such an honor.

About three years ago, or thereabouts, when a certain nominating committee met and I was approached on the idea of becoming your Second Vice-President, I think I was quite frank in expressing all of the reasons that occurred to me why the WELDING SOCIETY should not consider me as one of their national officers. They were considerable, and in addition to that, I can think of a great many personal reasons why I did not wish to undertake the responsibility of it—the very considerable responsibility that is involved in the position.

Apparently these reasons were not as effective as I thought, and in the years succeeding two more nominating committees have committed the same blunder.

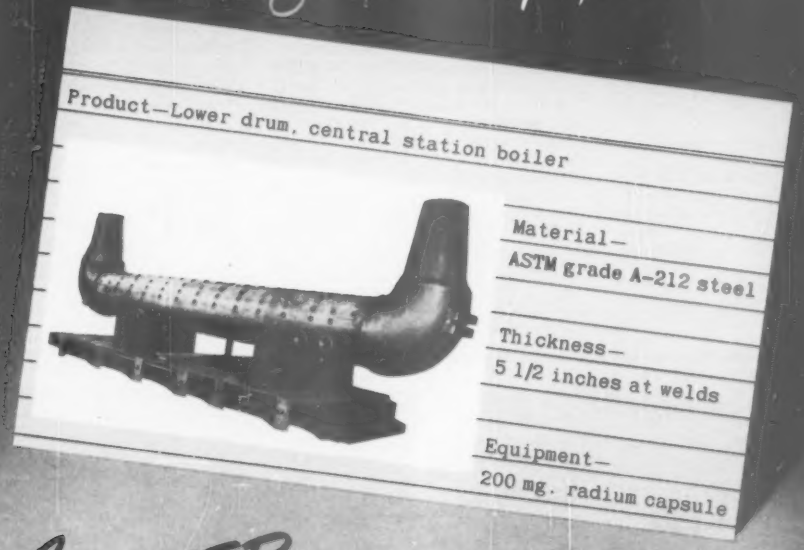
At least, however, it leaves me in a good position. I have made no campaign promises. None have been asked. I was not asked to give a platform. There is probably no one in the room who knows what I am going to do. I hate to add, including myself.

I might say that over the past few months since the election results have come in, that I have received plenty of advice. I regret to say that the advice is a bit diverse. I have never yet succeeded in going down a road in opposite directions at the same time, which indicates here some of the problems that lie ahead of Mr. Jennings, Mr. Plummer and the rest of the officers, and myself.

I believe that I have certainly expressed in the last twenty years an appreciation of all the activities of the SOCIETY. I have been exceptionally fortunate in one way or another in being mixed up in Section affairs in Headquarters and in the Technical Activities Committee; all too briefly and without distinction. I have been interested in the JOURNAL, in educational activities, and everything else, so that I at least have no preconceived notions of which is more important.

It is my program, more simply expressed, to accomplish the objectives of the SOCIETY, and I regard the position of the officers, Charlie Jennings, Fred Plummer and myself in this way. The execution of those objectives is in responsible

What's the right X-Ray film?



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To provide the recording medium best suited to any combination of radiographic factors, Kodak produces four types of industrial x-ray film. These furnish the means to check welds efficiently and thus extend the use of welding processes.

Type K has medium contrast with high speed. For gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without calcium tungstate screens.

Type M provides maximum radiographic sensitivity, high contrast, and exceptional detail under direct exposure or with lead-foil screens. It has extra fine grain and the speed is adequate for examination of light alloys at average kilovoltage and for much million-volt radiography of steel and heavy alloys.

Type A offers high contrast with about three times the speed of Type M, but with slightly more graininess. Used direct or with lead-foil screens for study of light alloys at low voltages, and of heavy steel parts at 1000 kv.

Type F provides the highest available speed and contrast when exposed with calcium tungstate intensifying screens. Has wide latitude with either x-rays or gamma rays, exposed directly or with lead-foil screens.

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hands; experienced hands. It is our job merely to direct, coordinate it, wherever necessary and assist where we can in providing the means.

I am a bit humble in my own estimate of my ability to do all those things. I can only say that I shall do the best I can. Whether we agree on the methods or not, I bespeak the help of every friend of mine in the SOCIETY. Thank you.

Western Metal Congress

More than 200 metal firms will show their new products and latest developments at the Seventh Western Metal Exposition to be held for five days—March 19–23, 1951, in Oakland's vast Auditorium and Exposition Hall.

On the same dates, approximately 100 authoritative speakers will deliver papers on recent developments in making, working, fabricating, treating and application of metals. These speakers will be heard at technical sessions of the Western Metal Congress, also to be held in Oakland—for the seventh time on the Pacific Coast.

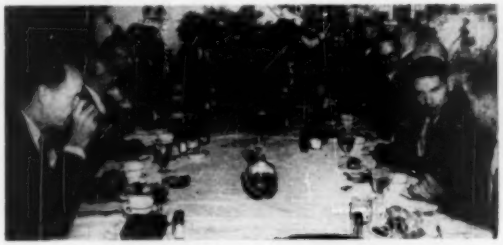
Announcements pertaining to the double event just have been made by William H. Eisenman, of Cleveland, secretary, American Society for Metals. The show and congress will be sponsored as in the past, he said, by the A.S.M. in cooperation with 20 other national technical societies.

Eisenman, who managed the six previous western metal events and directed the National Metal Exposition and Congress at 32 successive showings, expects to be in the West by December 1. His headquarters until end of the meeting will be in Exposition Hall, 918 Fallon St., Oakland 7, Calif.

In keeping with increased demands imposed on the metal industry, the theme for exhibits and speakers will be "Production for America." Displays and papers will be based on application of metals in the oil, chemical, manufacturing, aviation, construction, mining and other industries.

Eisenman reports that considerably more than 50% of exhibit space already has been assigned to western, midwestern and eastern producers. Many national concerns which produce metals, machinery and testing equipment have reserved display areas. The balance of space doubtless will be "inked in" shortly after Eisenman arrives in Oakland.

Snapshots Taken at Meetings of Ship Structure Sessions Through the Courtesy of the Coast Guard Public Information



Ship Structure Committee Luncheon held in connection with the Ship Structure Symposium at the Annual Meeting of the American Welding Society

Part of Audience at Ship Structure Symposium held in connection with the Annual Meeting of the American Welding Society, October 24, 1950

Rear Admiral K. K. Cowart

Captain C. M. Tooke

U. S. Navy Photos

Comdr. R. D. Schmidtman

1940-1950

10 YEARS OF PROGRESS...
and phenomenal user acceptance

Low Temperature **EUTECTIC** WELDING ALLOYS

I should like to thank the welding engineers and the welders of America who have so wholeheartedly supported our efforts. I should also like to renew our pledge of never-ceasing research and continued production expansion in the development of rods, electrodes and fluxes that will bring even greater advances in increased speed, safety, and savings to your welding operations.

Cordially yours,

Reno J. Wasserman
President

Forty-four years ago, my father began research on a method of joining metals at heats below the melting point of the base metals involved. Later on, I had the privilege of continuing this work with him to the point where we perfected a new metal-joining process utilizing an entirely different kind of welding rods and electrodes that yield radically new results.

To distinguish our new line of filler metals, we coined the phrase, "Low Temperature WELDING ALLOYS", which is registered in the U.S. Patent Office as a Trade Mark of this company.

When, in 1940, these vastly improved techniques were introduced to American industry, it was my privilege to establish and to guide a basic policy that was to keynote our activities for the next decade: "CONTINUOUS RESEARCH AND SERVICE".

Today, in our tenth year of uninterrupted progress, the results of that unceasing determination to overcome the failures of old-fashioned, high-heat welding methods may be measured in many ways.

One gauge of effectiveness lies in the long list of EUTECTIC's developments that have become veritable "milestones" in the advancement of American welding techniques:

✓ The first nickel-bearing, copper zinc welding alloy. (U.S. Patents No. 2,279,282 and 2,279,283)

✓ The first nickel-bearing, copper zinc welding alloy containing silver. (U.S. Patent No 2,279,284)

✓ Truly color-matching process for welding cast iron at low heat. (U.S. Patent No. 2,288,869)

✓ Low-melting, high silicon content, aluminum joining alloy for use with specially compounded flux. (U.S. Patent No. 2,481,053)

✓ Low-melting flux specially compounded for use in the welding of ferrous metals. (U.S. Patent No. 2,479,798)

✓ Covering of welding rods with special metallic film. (U.S. Patents No. 2,359,813 and 2,410,850)

✓ Fully machinable, low-amperage electrode for welding cast iron. (U.S. Patent No. 2,410,850)

✓ High-strength electrode for welding aluminum without spatter or fumes. Trademarked: "EutecTrode 2101." (U.S. Patent Pending)

✓ High Quality fluxes used in conjunction with gas rods and electrodes for the welding of aluminum, aluminum alloys and magnesium. Trademarked: "Eutector."

✓ Series of low-melting alloys for color-matched joining of aluminum, brass, bronze, copper, and nickel alloys.

✓ AC-DC cutting electrode that cuts, pierces, chamfers all metals without oxygen. Trademarked: "CutTrode."

✓ Mass-produced 'contact-type' electrode for swifter, safer welding of steel. Trademarked: "Hand-O-Matic."

✓ 'Easy-to-use' electrode for multiple-pass welding of mild steel without intermediate slag chipping. Trademarked: "Steel-Tectic."

These are only a few out of the full list of over 150 job-proved alloys our company offers today.

Today, as we start our second decade of service to American Industry, EUTECTIC Low Temperature WELDING ALLOYS are specified in over 78,000 plants throughout the nation!

EUTECTIC originated the program of FREE Consultation-Demonstration in your shop. Today, 200 well-trained District Engineers stand ready to serve you from Coast to Coast whenever you say the word.

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Preparations are made for a large attendance. The exposition again will enable plant operators, industrial executives, engineers, production men and purchasing agents to conveniently study the progress made in metal products and metal handling throughout the United States.

Technical advances achieved in the same period will be discussed with clear precision at sessions of the congress. In Eisenman's opinion, the program will be the most informative and beneficial to industry of any yet presented on the Coast.

Societies cooperating with A.S.M. in presenting the exposition and congress include:

American Chemical Society, American Foundrymen's Society, American Institute of Chemical Engineers, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Society of Tool Engineers, AMERICAN WELDING SOCIETY, Institute of Aeronautical Sciences, Mining Association of California, National Association of Corrosion Engineers, National Association of Lubricating Engineers, Pacific Coast Electrical Association, Pacific Coast Gas Association, Purchasing Agents' Association of Northern California, Inc., Society of Automotive Engineers, Society for Non-Destructive Testing and Western Oil and Gas Association.

Final 1949–50 Board of Directors Meeting

The final meeting of the Board of Directors of the AMERICAN WELDING SOCIETY for the year 1949–50 was held at 1:20 P.M. in the Jade Room of the Hotel Sherman, Chicago, Ill., on Thursday, Oct. 26, 1950, with the following in attendance:

Members: O. B. J. Fraser, H. W. Pierce, C. H. Jennings, F. L. Plummer, R. S. Donald, D. Arnott, J. J. Chyle, A. F. Davis, J. Grodrian, T. B. Jefferson, C. I. MacGuffie, A. J. Moses, G. S. Schaller, G. N. Sieger, L. C. Stiles, J. B. Tinnon and R. L. Townsend.

Guests: A. G. Bissell, T. J. Crawford, L. Grover, H. E. Rockefeller, J. R. Stitt, C. B. Voldrich and A. E. Wisler.

By Invitation: C. D. Evans, A. G. Oehler, W. Spraragen, A. C. Weigel and J. L. Wilson.

A.W.S. Staff: J. G. Magrath and F. J. Mooney.

The following Members did not attend: C. A. Adams, L. C. Bibber, W. F. Boyle, C. E. Claussen, L. W. Delhi, H. O. Hill, J. H. Humberstone, T. M. Jackson, H. N. Simms and H. S. Swan.

Expression of Thanks Extended to Retiring Board Members

Retiring President O. B. J. Fraser extended the appreciation of the President, Officers, Board Members and the SOCIETY to those Members of the Board of Directors now retiring for their valued services, namely, G. E. Claussen, R. L. Townsend, D. Arnott, T. M. Jackson, C. I. MacGuffie, J. B. Tinnon and L. W. Delhi.

Introduction of Newly Elected Members of the Board of Directors

Newly elected Officers, Directors-at-Large and District Vice-Presidents were announced by Mr. Fraser and requested to rise. Announced were Second Vice-President F. L. Plummer; and Directors-at-Large L. Grover, H. E. Rockefeller, J. R. Stitt and C. B. Voldrich; and District Vice-Presidents A. G. Bissell (District No. 2), T. J. Crawford (District No. 4) and A. E. Wisler (District No. 6).

Acceptance of Minutes of Executive Committee Meeting Held on Sept. 21, 1950

Report of Committee on Election Procedure: Considerable discussion ensued relative to the A.W.S. Constitution and By-Laws Committee's recommendation on report as rendered to their Committee by the Special Committee on Election Procedure and as approved by the Executive Committee at meeting held on Sept. 21, 1950.

A. C. Weigel, Chairman of the Special Committee on Election Procedure, and J. B. Tinnon, member of this Committee, voiced disapproval on changes made to the report by the Constitution and By-Laws Committee. They contended that the scope of the Constitution and By-Laws Committee is limited to receiving suggestions for revisions to the Constitution or By-Laws and responsibility for the preliminary wording of such revisions. They

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to get

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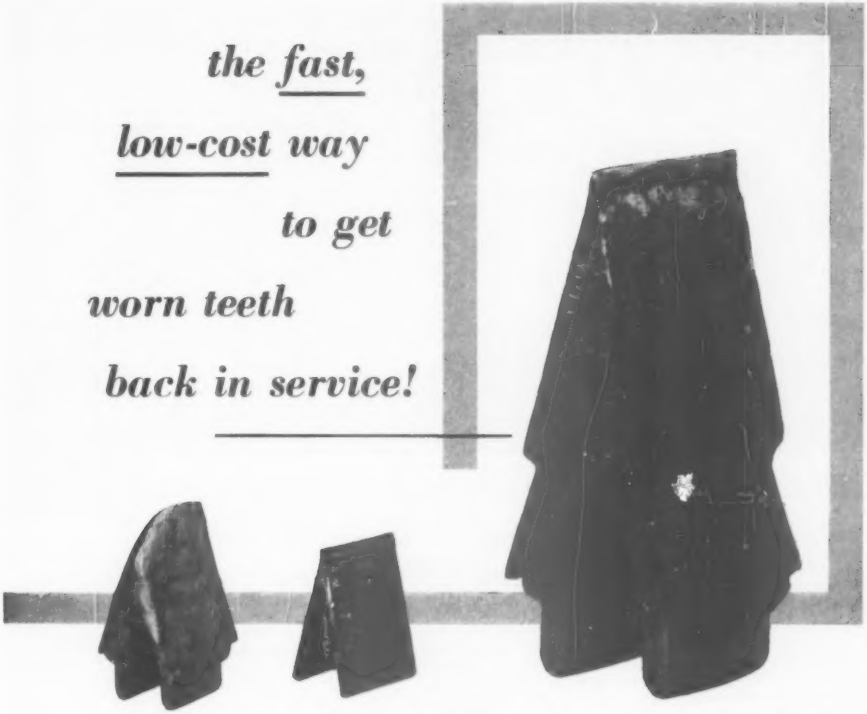

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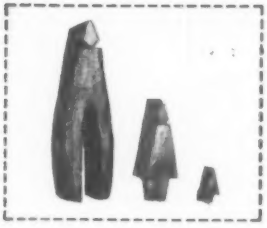

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Wherever equipment has teeth that wear, more and more owners are using money-saving AMSCO Tooth Repointers . . . available in a wide variety of styles and sizes.

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contended that the Constitution and By-Laws Committee did not have authority, under this scope, to alter recommendations referred to their Committee.

The Board of Directors upon motion, duly seconded, referred the report of the Special Committee on Election Procedure to the incoming 1950–51 Constitution and By-Laws Committee for reconsideration of the referendum and for preparation of their recommendations for rewording the SOCIETY'S By-Laws, such wording to be in accord with the intent of the recommendations of the Special Committee on Election Procedure.

Life Members: The Board of Directors, upon motion, duly seconded, voted the deletion of sentence which reads "(Student Membership years not included)" from Section 2—Qualifications and Privileges—of the SOCIETY'S By-Laws as this sentence was included in error.

Recommendations of Technical Activities Committee

The Technical Activities Committee at meeting held on Oct. 11, 1950, voted as follows:

"To recommend to the Board of Directors that S. A. Greenberg be appointed as Alternate to the American Welding Society representative, LaMotte Grover, on A.S.A. Sectional Committee A-57—Building Code Requirements for Iron and Steel."

The Board of Directors so approved.

"To recommend to the Board of Directors that the invitation to appoint an AMERICAN WELDING SOCIETY representative to the Steel and Iron Panel of the Commerce and Industry Association be accepted and that S. A. Greenberg be appointed official AMERICAN WELDING SOCIETY representative."

The Board of Directors so approved.

"To recommend to the Board of Directors that the invitation to appoint an AMERICAN WELDING SOCIETY representative to A.S.T.M. Committee on Methods of Sampling and Testing Relating to Atmospheric Pollution be accepted and that H. F. Reinhard, Union Carbide and Carbon Corp., be appointed official AMERICAN WELDING SOCIETY representative and that S. A. Greenberg be appointed as Alternate representative to H. F. Reinhard."

The Board of Directors so approved.

Increase in The Welding Journal Advertising Rates

THE WELDING JOURNAL Committee at a meeting held on Sept. 26, 1950, voted to recommend to the Board of Directors that an increase in advertising rates of approximately 30% be put in effect on new contracts at once (Oct. 2, 1950), "until forbid" contracts Jan. 1, 1951, and firm contracts on expiration.

The Executive Committee in the interim, as an emergency measure, via telephone conversation, voted favorably on increase in rates and advised the Secretary to issue a notice of increase in advertising rates in the order recommended by THE WELDING JOURNAL Committee.

The Board of Directors fully cognizant of recent increases in paper and printing costs, and aware of the emergency faced by the Executive Committee, upon motion, duly seconded, approved of recommendations of THE WELDING JOURNAL Committee and the action of the Executive Committee with respect to an increase in advertising rates of approximately 30% in the order mentioned above.

Increase in Subscription Rates and Single Copies of THE WELDING JOURNAL

THE WELDING JOURNAL Committee recommended that the Board of Directors approve the following: (1) Domestic annual subscription rates be increased from $5.00 to $6.00; (2) Foreign annual subscription rates be increased from $7.00 to $7.50; (3) Price of single copies to Members be increased from 50¢ to 75¢; (4) Price of single copies to nonmembers be increased from 75¢ to $1.00. Foregoing rates to become effective Jan. 1, 1951.

The Board of Directors so approved.

Honorary Membership for Robert T. Gillette

The Committee on Honorary Membership and Honorary Directorship recommended to the Board of Directors the name of Robert T. Gillette for Honorary Membership in the SOCIETY in recognition of his thirty years of outstanding service in industry and especially in the field of resistance welding.

Upon motion, duly seconded, the Board of Directors unanimously elected Mr. Gillette to Honorary Membership in the SOCIETY. Accordingly, President Fraser appointed a committee, of two, consisting of Dr. W. F. Hess and R. W. Clark, to prepare proper wording to be inscribed on Honorary Membership certificate to be presented to Mr. Gillette.

Enlargement of Technical Activities

Messrs. C. D. Evans and J. Lyell Wilson, Chairman and Vice-Chairman of the Technical Activities Committee, respectively, summarized proposals made by the Technical Activities Committee at a previous meeting of the Finance Committee and Board of Directors. They observed that it was impossible for the T.A.C. to either do the things as planned for or to show results expected of it without strengthening its organization by the added personnel requested in its presentation to the Finance Committee at meeting held on Aug. 22, 1950. The added personnel recommended by the T.A.C. at that meeting was in the order of employment of an assistant to the Technical Secretary.

Considerable discussion ensued and it was the general opinion of the attending members that the T.A.C. program should be enlarged in order to effectively accomplish its mission.

Upon motion, duly seconded, the Board of Directors voted approval of the withdrawal of an amount not to exceed $10,000 from the Reserve Funds Account in order to carry out the proposed program of the Technical Activities Committee.

Announcement

President Fraser announced that upon adjournment the 1950–51 Board of Directors would convene immediately and that H. W. Pierce, newly elected President, would preside as Chairman.

Adjournment

The meeting was adjourned at 3:30 P.M.

First Board of Directors Meeting for 1949–50

The first meeting of the Board of Directors of the AMERICAN WELDING SOCIETY for 1950–51 was held in the Jade Room of the Hotel Sherman, Chicago, Ill., at 3:30 P.M., on Thursday, Oct. 26, 1950. The following attended:

Members: H. W. Pierce, C. H. Jennings, F. L. Plummer, R. S. Donald, A. G. Bissell, J. J. Chyle, T. J. Crawford, A. F. Davis, O. B. J. Fraser, J. Grodrian, L. Grover, T. B. Jefferson, A. J. Moses, H. E. Rockefeller, G. S. Schaller, G. N. Sieger, L. C. Stiles, J. R. Stitt, C. B. Voldrich and A. E. Wisler.

A.W.S. Staff: J. C. Magrath and F. J. Mooney.

The following Members were absent: C. A. Adams, L. C. Bibber, W. F. Boyle, H. O. Hill, J. H. Humberstone, H. N. Simms and H. S. Swan.

Introduction

Mr. Pierce addressed the Board of Directors stating that he enjoyed working under the most industrious leadership of Mr. Fraser during his term of office and emphasized his desire to do as well as his predecessor, Mr. Fraser.

Mr. Pierce read the duties of the President from the SOCIETY'S By-Laws and stated he will follow through to the best of his ability.

Appointments—Officers

Upon motion, duly seconded, the following officers of the SOCIETY were reappointed for the administrative year commencing October 1950: *Secretary*, J. G. Magrath; *Assistant Secretary* and *Assistant Treasurer*, F. J. Mooney.

Designation of Officers to Sign Checks and Other Documents in Behalf of the SOCIETY

As prescribed by the By-Laws, the Board of Directors upon motion, duly seconded, voted to authorize the Treasurer and the President and, in the absence of either, the Assistant Treasurer, to sign checks, notes and other documents in behalf of the SOCIETY.

Appointments of Committee Personnel

Upon motion, duly seconded, committee personnel were officially appointed to serve for the 1950–51 administrative year.

Special Authority Extended to A.W.S. Executive Committee

The Board of Directors extended special authority to the Executive Committee of the AMERICAN WELDING SOCIETY for the 1950–51 administrative year by voting as follows: "An Executive Committee consisting of not less than five (5) members of the Board of Directors shall be em-

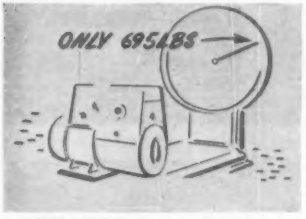
(*Continued on page 1142*)

P&H gives you

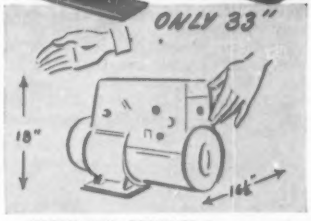
the only DC Arc Welder with *all* these tested time- and money-saving features

BUILT-IN REMOTE CONTROL Dial-lectric feature gives full arc-control at the work . . . saves operator's time . . . saves floor space for production.

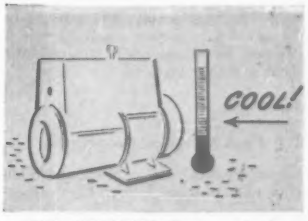
SLOW SPEED Lowest rpm per pound of weight. Only 1750 rpm for less wear, longer life, and minimum replacement costs. So quiet you hardly hear it.



LIGHT WEIGHT Easy to handle and move. Facilitates mounting off the floor and out of the way so there's more room for turning large weldments. Weighs only 695 lbs.



STURDY AND COMPACT Four sets of main brushes and one auxiliary set firmly fastened for good commutation. Simple design and rigid construction throughout . . . space-saving dimensions.



COOL OPERATION Slow speed plus extra large stator-frame cooling surfaces, and dual fans (for generator and motor) — make this the coolest welder you have ever seen.

● Stationary or portable mountings—Additional Features: single heat control; life-time sealed bearings; push-button start- and -stop switch with overload protection; high-low range switch; and polarity reversing switch. Get all the facts. Call your P&H representative, or send in coupon.

P&H **WELDING DIVISION**
Milwaukee 14, Wisconsin

Uniform, top-quality electrodes for every job!

HARNISCHFEGER CORPORATION

Specialized Training in
Metal Welding Fabrication
1 week to 18 months
Harnischfeger Welding Training School
in conjunction with
Milwaukee School of Engineering
Write to P & H today for further details
HARNISCHFEGER CORPORATION, Welding Division
4551 W. NATIONAL AVENUE • MILWAUKEE 14, WISCONSIN

EXCAVATORS • OVERHEAD CRANES • HOISTS • ARC WELDERS AND ELECTRODES • SOIL STABILIZER • CRAWLER AND TRUCK CRANES • DIESEL ENGINES • CANE LOADERS • PRE-ASSEMBLED HOMES

NEWS OF THE INDUSTRY

Aluminum Fellowship

Recognizing the value of extensive research in light alloys and their weldability which has been carried on at Rensselaer Polytechnic Institute since 1942, the Aluminum Company of America has established a $3500 fellowship at the Institute. Holder of the fellowship has not yet been named. A check for $3500 was presented on October 10th to Dr. Wendell F. Hess, head of metallurgy at the Institute, by Dr. E. H. Dix, Jr., assistant director of research in the company's New Kensington, Pa., laboratories.

Photomicrographs

A new release of photomicrographs has just been published by Eutectic Welding Alloys Corp. of New York to show welding engineers and operators exactly how and why Eutectic low-temperature welding alloys enable avoidance of the distortion, stress, warpage and embrittlement.

Reid Avery Officers

At a recent meeting of the Board of Directors of the Reid Avery Co., Inc., Baltimore, Md., the following officers were elected: Marshall E. Reid, Chairman of the Board; Chas. L. Virden, President; L. H. Christensen, Executive Vice-President; James M. Sawhill, Vice-President in Charge of Engineering; and Gerard E. Claussen, Vice-President in Charge of Research and Development.

Papers on Radiography

In an attempt to correlate late developments of radiography, the papers and discussions of a session on radiography at the 52nd Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., in 1949, have now been published. The radiography session was sponsored by A.S.T.M. Committee E-7 on Nondestructive Testing.

In his Introduction to the symposium, Leslie W. Ball says: "There has been a fascinating surge forward in two other aspects of this still young and vital technology. These rapidly developing aspects are in the engineering of radically new equipment and in the skilled exploitation of nondestructive testing in the management of engineering and material-processing development projects."

Copies of this 100-page profusely illustrated publication (STP 96) can be obtained in heavy paper cover, from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $1.75 each.

Applied Mechanics Reviews Transfers Editorial Offices

Effective with the October 1950, issue of *Applied Mechanics Reviews*, editorial responsibility has been transferred from the Illinois Institute of Technology, Chicago, Ill., to Midwest Research Institute, Kansas City, Mo., where the *Reviews* will be under the editorship of Martin Goland.

Applied Mechanics Reviews, now in its third year of operation, is published by The American Society of Mechanical Engineers and the following cooperating organizations: Office of Air Research, Midwest Research Institute, American Society of Civil Engineers, Institute of Aeronautical Sciences, American Institute of Physics, American Mathematical Society, Society for Experimental Stress Analysis, The Engineering Institute of Canada and The Institution of Mechanical Engineers (Great Britain).

This monthly *Reviews* journal, which presents critical reviews of the world literature in applied mechanics, has been hailed as a "must" tool for research personnel in universities, government and industrial research laboratories and industry in general, throughout the world.

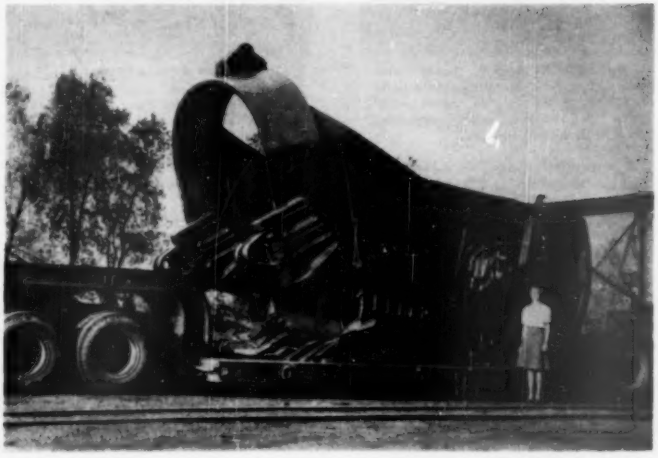
Drag Line Bucket

One of the largest all-welded, automatic drag line buckets in the country is shown ready for shipment.

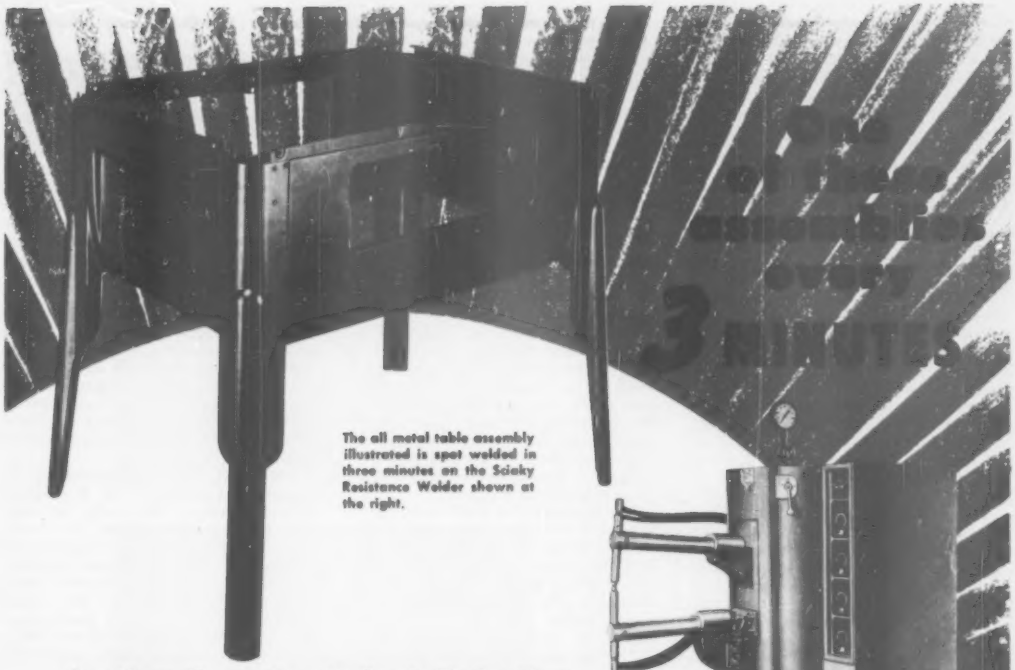
The 25-cu. yd. bucket is made of high-strength rolled steel and Hadfield castings. The bucket was manufactured by Page Engineering Co., of McCook, Ill., with electric arc-welding equipment.

Welded Bulkheads

Three welded steel floodway bulkheads, for use in a new lock chamber for Monongahela River Lock No. 2 at Braddock, Pa., recently were shipped from Dravo



(Photo courtesy of General Electric Co.)



The all metal table assembly illustrated is spot welded in three minutes on the Sciaky Resistance Welder shown at the right.

. . . Another Example of Cost Reductions Possible with Sciaky Resistance Welders

THE standard, moderately priced Sciaky resistance spot welder used to produce the all steel table pictured has returned its purchase price over and over again. One operator clamps the pieces, makes 72 spot welds and sets down a completed frame in 3 minutes. Contrast this with any other method of assembly!

This is not a special, high priced machine. It can be used for a tremendous variety of work—and with special jigs and fixtures the possibilities are almost limitless. For information on Resistance Welders to cut your costs, write today.

SCIAKY BROS., INC.
4921 W. 67th St. CHICAGO 38, ILL.

ABOVE: SCIAKY Model PMCRO Rocker Arm Spot Welders. KVA ratings: 20, 30, 40, 50, 75. Throat depths: 12", 18", 24", 30", 36". Welding Range: Mild Steel (two thicknesses) from .016"-.032" up to .016"-.125". You can't buy a better welder for the price than this exceptionally rugged, precision-built machine. One of a *complete* line of Spot, Seam, Projection and Flash Welders.

SINGLE PHASE OR THREE-PHASE units available. SCIAKY THREE-PHASE design reduces KVA demand 75% or more, provides a balanced load and a power factor near unity. Ask about it!

SEND FOR YOUR FREE COPY OF "RESISTANCE WELDING AT WORK" —containing actual plant studies of welding everything from roller skates to racing cars. Full of useful ideas on HOW TO CUT COSTS. Write today — no obligation.

Corp.'s Pittsburgh plant where they were fabricated by the company's Engineering Works Div. They are part of an order for metal work, controls, piping systems and machinery to be furnished by that division. Reconstruction of Lock 2, a vital project in the over-all program for improvement of Monongahela River navigation facilities, is being performed by The Contracting Division of Dravo Corp. for the U. S. Army, Corps. of Engineers.

Henry Ford Memorial Award

The Society of Automotive Engineers (Detroit Section) has announced a new award for the encouragement of younger engineers.

It is called the Henry Ford Memorial Award in honor of the late automobile manufacturer, who was always unremitting in his efforts to encourage the young engineer. The award was established by the Detroit Section, but any S.A.E. member under 33 years of age is eligible to compete.

Competition is by means of original papers which have been presented to, or are suitable for presentation to an S.A.E. meeting. Content of competing papers is limited to subjects related to automotive ground vehicles and must describe engineering work or investigation with which the author has been directly associated. The award consists of a suitable certificate of merit and a cash prize of $200.

A brochure, giving detailed information, has been prepared by the Society. Members desiring to compete may obtain copies through their local S.A.E. Section or by writing directly to the Detroit Section, Society of Automotive Engineers, 100 Farnsworth, Detroit 2, Mich.

Bridge Design Awards

The James F. Lincoln Arc Welding Foundation has announced awards of $10,750 in its 1950 Welded Bridges of the Future Program for the design of an all-welded 250-ft. highway bridge. Thirteen engineers and bridge designers have achieved international engineering recognition in the Program in competition with some of the foremost bridge designers in the world. The Program attracted designers from sixteen different countries, in many of which the building of welded bridges has been a necessity for over 20 yrs. in order to conserve steel.

The First Award of $5000 was given to James H. Jennison, 39, of Pasadena, Calif., Head of Development Engineering Div., U. S. Naval Ordnance Test Station. Second Award of $2500 went to Ernst Amstutz of Zurich, Switzerland. The Third Award, $1250, was given to Professor Thomas C. Kavanagh, 38, professor of Civil Engineering, Pennsylvania State College, State College, Pa., who in the 1949 Bridge Competition took First Award.

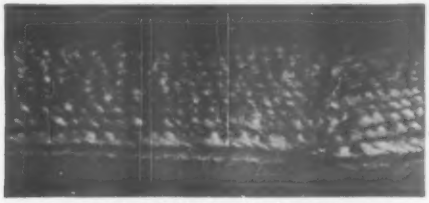
The Ten Honorable Mention Awards, each receiving $200, went to: M. S. Zakrzewski and J. R. Daymond, Durban, South Africa; Arsham Amirikian, Chevy Chase, Md.; John E. Kayser, Roseland, N. J.; J. W. Briscoe and E. R. Bretscher, Urbana, Ill.; Kazimierz Lecewicz and Wlodzimierz Gorgolewski of London and Wembley, England; John A. DeLong and A. A. Brielmaier, St. Louis, Mo.; John Turner Percy, Troy, N. Y.; Sidney Rochlin, Los Angeles, Calif.; I. L. Hamilton, Lanarkshire, Scotland, and Kenneth Warren Dobert, Troy, N. Y.

This Program is sponsored by the Lincoln Foundation to promote the building of better bridges for less money and with less steel. The rules of the Program were formulated to stimulate designers' ingenuity and originality in developing new design ideas, new shapes for structural steel members and new fabricating and erecting methods.

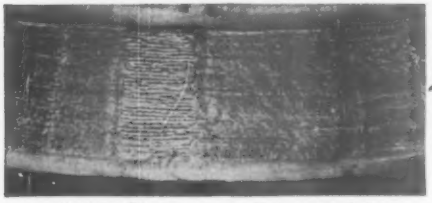
Dr. E. E. Dreese, Chairman of the Board of Trustees of the Foundation, states: "Bridges built today use more steel and are more expensive than is necessary because designs are based on old fabricating methods which do not utilize the strength of steel as completely as do designs based on welding. The welded bridges designed for this Program, it is estimated, could be built today with 20 to 30% less steel than would be required for equivalent riveted bridges."

BLAST FURNACE UNIT SHOWS NO WEAR

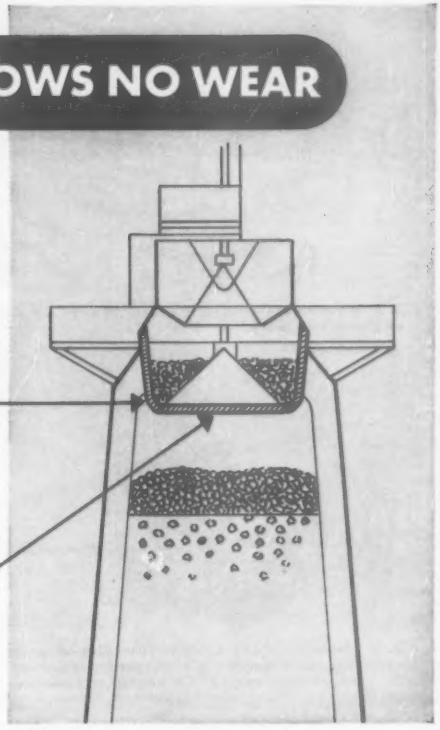
because both BELL and HOPPER were hard-faced with "HASTELLOY" alloy C



Close-up view of hard-faced surface of hopper.



Section of HASTELLOY alloy C deposit on bell.



After a year's service in a top-pressure blast furnace, the HASTELLOY alloy C surfaces on this bell and hopper unit show no signs of pitting, erosion, or wear. The unit resists the abrasive action of various charge materials and the effects of the 250 to 400 deg. F. top temperature.

HASTELLOY alloy C stays hard at the operating temperatures, and deposits made with this alloy maintain their resistance to checking and chipping. Surface hardness can be increased to as much as 400 Brinell by simple cold-working.

Alloy C has already increased the life of other types of steel plant equipment 10 times or more in such applications as blooming-mill hot shear blades, entry guides, twist guide rolls, angular-type guides, and dies and shafts. In these applications, as with the bell and hopper unit, hard-facing results in fewer shutdowns, less replacements, and greatly reduced maintenance costs.

Write for the booklet, "New Hard-Facing Techniques for Protecting Steel Mill Equipment from Wear." It describes some of the many hard-facing jobs that have resulted in large savings through use of HASTELLOY alloy C. In addition to HASTELLOY alloy C, there are many other HAYNES hard-facing rods—for practically every condition of wear, heat, impact, or severe abrasion. For information about any particular application that you may have in mind, contact the nearest Haynes Stellite District Office. Our engineers will be glad to help you.

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TRADE-MARK

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Los Angeles — New York — San Francisco — Tulsa

"Haynes," "Haynes Stellite," and "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

Fig. 1 First award design—a tied arch with a rise of 45 ft. at the center line, 13 panels and a stiffening tie girder

Arch ribs are 14 WF, hangers and K bracing 8-in. pipe

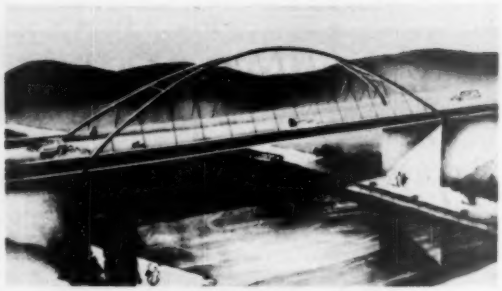

Fig. 3 Third award design—tied arch with arch ribs tilted in and splayed at the end

A single member is thus used over the center 40 ft. of the arch. Inclined stiffening girders to correspond to tilt of rib

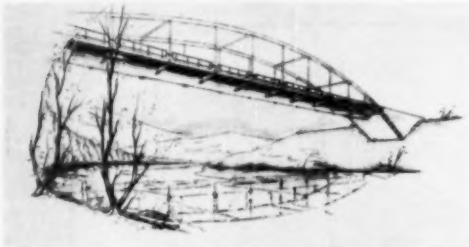

Fig. 2 Second award design—two hinged arch with a slender rib and a single stiffening girder of semicylindrical shape located at the center of the roadway

Honorable mention: design—tied arch with light arch ribs stiffened by 2 girders having a closed trapezoidal box section; made of two sloping web plates and single bottom flange; placed 13 ft. 4 in. c to c beneath roadway

This statement is substantiated, Dreese claims, by the many welded bridges that have been built in Europe and other parts of the world.

Professor Kavanagh, Third Award winner, in acknowledging the influence of European welded bridges on his design, said; "The importance of this tremendous backlog of successful experience in welded bridge construction in Europe cannot be emphasized too strongly to American Engineers, whose technical literature simply has not succeeded in getting across to its readers this truly remarkable story of achievement in welding."

Designs for the Program were judged by a Jury of Award of leading bridge designers, fabricators, public officials and professors of structural engineering.

for the best results at the lowest cost

BEST BUY BURDOX

In these days when cost has so much to do with profit, check with BURDOX first on your welding, cutting, or safety equipment. Feature for feature, every one of the hundreds of items in the BURDOX line gives you more service . . . yet costs you less for the same quality. For greatest savings—Best Buy BURDOX! For greatest savings—Best Buy BURDOX! Write for literature today!

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If it's for Welding or Cutting . . . We have it!

THE BURDETT OXYGEN COMPANY
3333 LAKESIDE AVENUE
CLEVELAND 14, OHIO

TWECO CABLE CONNECTORS

—"SOL-CON" (solder type)
—"MEC-CON" (mechanical)

Quick-detachable connectors. Add on cable. Take off cable. Attach holder whip cables. Split male plug permits adjusting spring tension for electrical contact. Two sizes, Sol-Con; three sizes, Mec-Con for #6 through 4/0 cable.

Tweco "Sol-Con" and "Mec-Con" plugs fit the female part of Tweco Terminal Connectors for quickly connecting cables to the welding machine and to switch polarity. They are COMPANION ITEMS

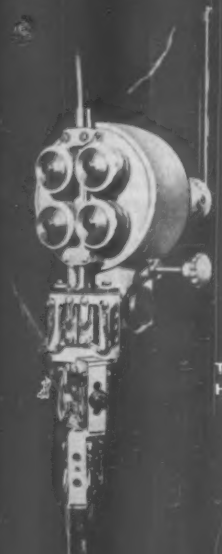
See Your Welding Supply Distributor

Tweco PRODUCTS COMPANY

TWECO PRODUCTS

WICHITA, KANSAS

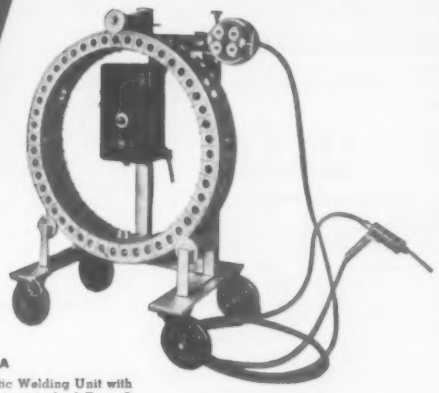
TWO NEW AUTOMATIC ARC WELDING HEADS



Type 4R Automatic Head and Control

THE REID-AVERY AUTOMATIC WELDING HEAD

THE REID-AVERY SEMI AUTOMATIC WELDING UNIT



Raco Type SA
Semi Automatic Welding Unit with reel and carriage to feed Type A heavily coated shielded arc wire. Capacity up to 1/8" wire.

TYPE 4R AUTOMATIC HEAD

The most universal welding head on the market today. Can be used with all types of automatic electrodes:—heavily coated shielded arc, lightly coated open arc. Also adaptable for submerged melt welding.

Can be used with any welding machine AC or DC.

The control is a self-contained unit with its own arc contactor for simplified wiring; just connect the welding machine cable to the arc contactor and plug in the control to the lighting circuit.

The head weighs only 38 pounds, has four driven rolls for positive feed without excessive wear or damage to wire coatings and 360° rotation with guide wheel—six mounting positions.

EXTREMELY SIMPLE CONTROL CIRCUIT
NO EXPENSIVE ELECTRON TUBES
NO EXTERNAL EXCITERS

TYPE S.A. SEMI AUTOMATIC WELDING UNIT

For those numerous jobs that do not warrant a full automatic welding fixture the REID-AVERY Type S.A. semi-automatic welding unit is ideal.

Designed to use the same electrodes as the full automatic head. The electrode is fed from the reel through a flexible tube to the welding gun at a rate proportional to the pre-set arc voltage. The operator merely guides the arc along the seam.

Note these advantages:—VISUAL ARC. Higher currents and speeds than are possible with manual electrodes—no craters in long seams—no stub end losses—simplified wiring, just connect the welding cables and plug into the lighting circuit—large rubber tired casters on carriage for portable operation.

Write For Descriptive Bulletin

The REID-AVERY COMPANY
INCORPORATED
DUNDALK • BALTIMORE 22 • MARYLAND

It is the sales policy of The Reid-Avery Company, Inc., to market our products exclusively through distributors and agents. • *Members of* THE AMERICAN WELDING SOCIETY *and* THE NATIONAL WELDING SUPPLY ASSOCIATION

NEW LITERATURE

National Welding Equipment Co. Catalog

An unusual brochure of a company's products departs from the usual catalog style and prepare to sell merchandise in the welding industry has been issued by the National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif. Copy available on request.

Powder-Cutting and Scarfing Processes

A new 8-page illustrated booklet, "Powder-Cutting and Scarfing Processes," has been announced by The Linde Air Products Co., a Unit of Union Carbide and Carbon Corp. The booklet describes applications of these processes in the fabrication of stainless steel. Other uses discussed are the powder cutting of heavy steel scrap and nonferrous applications. The chemistry, metallurgy and equipment used in the process are described in detail.

This booklet may be obtained without charge from the nearest office of The Linde Air Products Co., or by writing direct to the main office, 30 E. 42nd St., New York 17, N. Y.

Metallizing Saves Time and Money

The current issue of the *Metco News* shows how Metcoloy No. 2, high-chrome, high-carbon stainless steel alloy is saving many hours and dollars for metallizing users. It owes its popularity to a fine service record as a wear-resistant coating under severe operating conditions involving abrasive and corrosive materials. Its resistance to corrosion makes it the logical choice for the repair of turbine shafts, pump rods or impellers, rams, rolls, etc.

Write for your copy of the *Metco News* Vol. 5, No. 4, Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Delta Catalog

A new 60-page Delta catalog has recently been issued, according to word from the Delta Power Tool Division, Rockwell Mfg. Co., Milwaukee 1, Wis. The catalog pictures and describes the new, fully-automatic, air-operated Delta-Milwaukee 5 kva. spot welder and other tools in the broad Delta line of 53 machines, 246 models, more than 1300 accessories.

A free copy of the AB-50 catalog can be obtained from Delta-Milwaukee dealers or by writing direct to the company.

Flame Hardening Catalog

A new flame-hardening apparatus catalog has been announced by Air Reduction Sales Co., A Division of Air Reduction Co., Inc.

Descriptions and illustrations of the latest flame-hardening equipment are contained in this 20-page catalog. It has been expanded to include a section on "Tips for the Production Flame Hardening of Special Shapes." Gas control equipment and pipe-line systems are discussed.

For a free copy of this new catalog, write the Airco Sales office nearest you, or Air Reduction, 60 East 42nd St., New York 17, N. Y.

Capacitors for Industry

Capacitors for Industry is a book of 246 pages published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.

This book deals with capacitators for industry, their selection, application and economics for power-factor improvement of industrial plants.

The book was prepared by W. C. Bloomquist, C. R. Craig, R. M. Partington and R. C. Wilson; and was edited by W. C. Bloomquist.

Included is important information on the practical applications of capacitors in industry, including resistance welding, with useful tables, curves and illustrative examples for speedy and accurate solutions.

Price $4.50.

"Heliarc" Welding in the Automotive Industry

A new 12-page booklet, "Heliarc Welding in the Automotive Industry," has just been announced by The Linde Air Products Co., a Unit of Union Carbide and Carbon Corp. This booklet summarizes the basic advantages of the inert-gas-shielded-arc welding process for automotive work, particularly the reductions in finishing costs and the simplification of drawing and stamping operations. It describes in considerable detail several applications of the process already well established in the automotive industry. Information is given on fixture and equipment requirements, methods, procedure and welding costs. The booklet is well illustrated with actual on-the-job photographs.

Copies of this booklet can be obtained without cost by writing the nearest office of The Linde Air Products Co. or the General Office at 30 E. 42nd St., New York 17, N. Y.

Tungsten Electrodes

Bulletin 1.102-1, "Fansteel Tungsten Electrodes for Inert-Gas Welding," has just been issued by Fansteel Metallurgical Corp., North Chicago, Ill.

In addition to listings of standard diameters and lengths in which Fansteel tungsten electrodes are supplied, the bulletin contains seven practical suggestions for longer electrode life, better welds, labor saving and lower welding costs.

Copies of this bulletin will be supplied upon request.

Application of Arc Welding

Elektriska Svetsningsaktiebolaget, Goteborg, Sweden, has issued a handsome deluxe book, journal size, with hard paper covers, consisting of 327 pages, copiously illustrated with a number of insert pages, giving the best papers presented in an international prize competition on the rational and effective application of arc welding. The rules of the competition provide for papers covering the application of arc welding in the redesign and the new design of steel structures. The book is divided into six sections as follows:

I. Machinery (inclusive of electric machinery).
II. Shipbuilding.
III. Aircraft.
IV. Bridges, structural buildings, hydraulic structures, houses.
V. Conveyance and transport devices.
VI. Large pressure vessels, containers and piping.

The section on bridges contains the results of large comprehensive programs of research dealing with fatigue and metallurgical examinations of ordinary steel and high-strength steel used in bridge construction. The book is an asset to any library on welding.

How to Weld with Heliarc Torches

"How to Weld with Heliarc Torches" is a newly revised booklet containing information on welding, surfacing and hard-facing of many commercially used metals. Chapters are included on the fundamentals of the process, a description of the Heliarc equipment, preparations for welding, operating instructions for handling the torches, and complete welding data for aluminum stainless steel, magnesium, copper and copper alloys, plain carbon and low alloy steels, cast iron, and nickel and Monel.

Properties of each metal and precautions for welding them, sketches showing the types of welds and thickness of materials, detailed tables of welding current, welding rod, electrode diameter, torches and welding speed to be used for the various thicknesses and types of joints are all included in 12 pages of detailed information.

This 28-page booklet, F-6190, is available on request from The Linde Air Products Co., 30 E. 42nd. St., New York 17, N. Y.

PERSONNEL

Jefferson Becomes Advisor

T. B. Jefferson, editor of *The Welding Engineer* and *The Welding Encyclopedia*, has been appointed to the advisory committee of the Welding Institute at the Milwaukee School of Engineering, according to Karl O. Werwath, School president. Jefferson, is a graduate mechanical engineer from the University of Kansas and has been closely associated with the structural steel, metal fabricating and welding industries for many years.

Grable Joins Battelle

Godfrey B. Grable has been appointed to the staff of Battelle Institute, Columbus Ohio, where he will be engaged in the Institute's program of welding research.

Mr. Grable was formerly associated with the Bureau of Ships and the Bureau of Aeronautics as metallurgist and materials engineer. He is also a former member of the research staff of the A. O. Smith Corp.

He is a graduate of the University of Kansas and is a member of the AMERICAN WELDING SOCIETY and the American Society for Metals.

James I. Banash Elected Fellow of ASME

The American Society of Mechanical Engineers has honored James I. Banash by electing him to the grade of Fellow of the Society. To be qualified as a nominee to the grade of Fellow one must be an engineer who has acknowledged engineering attainment, 25 years of active practice in the profession of engineering or teaching of engineering in a school of accepted standing and has been a member of the Society for 13 years. Promotion to the grade of Fellow is made only on nomination by five Fellows or members of the Society to the Council, to be approved by Council.

James I. Banash, consulting engineer, Chicago, Ill., is one of the country's foremost authorities in the field of safety and fire and accident prevention. He has specialized in fire and accident prevention in their relation to the physical and chemical sciences. Several years ago he achieved prominence for his work with artificial atmosphere high in oxygen, in relation to therapeutic application. He was with Underwriters' Laboratories, Inc., Chicago, Ill., for 12 years and became head of the casualty department. He is consulting engineer for the National Acetylene Assn. and is an active member of many other engineering and research societies. He was one of the founders of the AMERICAN WELDING SOCIETY. Mr. Banash has written many papers on oxygen and acetylene welding and cutting; safety, oxygen therapy, liquefied-petroleum gases and various uses of containers for compressed gases.

Mr. Kneiper Now in Argentina

James S. (Jim) Kneiper, Welding Supervisor for the Construction Department of the M. W. Kellogg Co., for the past five years, is now associated with the Kellogg Pan American Corp. as Metallurgical Engineer. He is located at present in La Plata, Republica Argentina, where he is working on the construction of a refinery for the Argentine Government. He would like to hear from his friends in A.W.S. and may be reached at Calle 7, Number 1792, La Plata, Republica Argentina.

"Anton L. Schaeffler Joins Allis-Chalmers Mfg. Co.

After six years as Metallurgical Engineer for the Arcos Corp. in Philadelphia, Tony Schaeffler has returned to his home town and is now working for the Allis-Chalmers Mfg. Co. in Milwaukee. He was in charge of the Metallurgical Department of Arcos Corp. and specialized in the welding metallurgy of stainless, low-alloy and dissimilar steels.

His present position is Welding Metallurgist for the Chemical and Metallurgical Department of Allis-Chalmers. This department is responsible for initiating new procedures and handles production control for the vast West Allis Works.

Prior to his position with Arcos, Mr. Schaeffler received his cooperative training at Harnischfeger Corp. while studying at Marquette University. Following graduation he spent three years with A. O. Smith Corp. and also received his M.S. in Metallurgical Engineering from the University of Wisconsin.

OBITUARY

Keith Winsor

On the 18th of June, 1950 with tragic suddenness, the death occurred in England of Keith Winsor, General Production Manager of The Commonwealth Industrial Gases, Limited, Electric Section, Australia. Mr. Winsor was on a visit to England when his death occurred.

He leaves a widow and young son, Leigh, and to them and to the members of his own family we extend our deepest sympathy. Mr. Winsor was a member of the AMERICAN WELDING SOCIETY.

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White Plains, New York

NEW PRODUCTS

Film Drier

A new-type film drier that is ideally suited to the small X-ray department has been announced by the General Electric X-Ray Corp., Milwaukee, Wis.

Priced 20% below its predecessor model, the new Aridair Drier is also considerably quieter, less subject to rusting, much faster drying and greatly improved in design and appearance.

Dual 300/600 and 400/800 Ampere Selenium Rectifier D.-C. Welders

New dual 300/600 and 400/800 ampere selenium rectifier d.-c. welders are available from Westinghouse Electric Corp.

Each dual unit offers two welding circuits in one common enclosure. These circuits may be used independently, or in parallel to provide a single circuit of twice the capacity.

Parallel operation of the two units for maximum capacity is obtained by means of a bridle placed across the secondary output terminals. A clutch-and-sprocket and chain arrangement makes possible independent or unit operation of the current control handles on each individual welder.

A primary contactor is supplied to facilitate use of these machines on automatic and stud welding applications.

For further information write Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.

New Steel

A new steel exceptionally strong for either peace or war use has been developed by the Research Laboratory of Carnegie-Illinois Steel Corp., largest subsidiary of United States Steel. With good resistance to corrosion, it remains tough even at temperatures below zero where many structural materials tend to show some loss of toughness.

Bearing the grade designation "T1," this new "Carilloy" steel composition was developed for possible use in the construction of ships and heavy mobile equipment. The development was also encouraged by the manufacturers of heavy earth-moving and surface-mining machinery, for which the steel's toughness helps to prolong seasonal operations up to the time when winter cold actually freezes earth and ores.

With almost double the strength of the high-strength, low-alloy steels, "Carilloy" T1 will effect savings in mobile equipment, since the steel can be made in quantity in standard open hearth furnaces. It may be welded easily with welding electrodes that are now available; yet it possesses almost triple the strength of ordinary welding-grade structural steels. It was designed to provide at least two to three times the resistance to atmospheric corrosion offered by plain carbon steels.

Research, looking to the development of "Carilloy" T1, was begun more than four years ago. Many experimental laboratory heats were made as the development proceeded, each series of heats introducing new and valuable properties to the over-all composition. Finally, following the laboratory experimentation and testing, large commercial heats were recently made.

Special attention was given to the conservation of costly and strategic alloying materials in the design of "Carilloy" T1. Its strength is drawn from small quantities of a comparatively large number of alloying elements that are readily available. It was made hardenable by the application of lessons learned during World War II.

While it has many valuable properties, "Carilloy" T1 is not a "trick" steel, requiring unusual handling. No special equipment or procedures are necessary for its fabrication. It may be bent or formed cold with sufficient power to overcome its high strength. Countless tests have proved that welding does not adversely affect its properties. Thus it is more versatile than steels that must be riveted.

"Carilloy" T1 is basically a plate steel but may be produced in other forms.

With almost double the strength of high-strength, low-alloy steels and almost triple that of ordinary welding grade structural steels, "Carilloy" T1 promises to effect considerable savings in applications calling for heavy steel members of $\frac{1}{2}$ in. thickness and up.

This plate steel is furnished heat treated to a minimum yield strength of 100,000 psi. It maintains adequate toughness even at this high level of strength and is suitable for application where extreme high strength and good weldability are required.

It has been established definitely that welding does not adversely affect the properties of this steel, which has been designed to require no special preheating or post-heating treatments in welding or gas-cutting operations beyond those normally used with ordinary structural steels. If low-hydrogen type electrodes are used, "Carilloy" T1 is not susceptible to underbead cracking. Electrodes that will develop the full strength of the T1 basic metal are available and should be used if 100% joint efficiency is needed.

It has now been established that ordinary room temperature testing procedures will not adequately predict the behavior of welded structures under adverse conditions of restraint or when used at low temperatures. For this reason, an extensive testing program was initiated on this steel, utilizing various types of tests to determine its tendency toward brittle failure under various conditions. The results of this testing program indicate that "Carilloy" T1 possesses excellent toughness under such conditions. This feature gives the user added insurance against brittle failure.

The unique properties of this new steel are obtained by blending multiple alloying elements, coupled with precision heat treatment. Carbon content is restricted to 0.18 maximum to promote ease of welding and gas cutting.

Bi-Colored Lenses

American Optical Co., Southbridge, Mass., announces it is making available new bi-colored fused lenses designed to protect the eyes of workers engaged in heat treating and furnace operations, scarfing and burning operations, some open hearth and blast furnace operations, kiln processes and welding.

In comparison with the older two-piece bi-colored lenses, the new fused lenses can be replaced more easily and quickly in goggle frames. Instead of fitting two half-lenses, the single lenses can be fitted in a fraction of the time. The fusing process at the same time eliminates all possibility of light streaks being present.

Because the lenses are fused into a strong solid piece, uniform thickness is assured, and there are no rough edges. Of AO Super Armorplate quality, the new one-piece lenses are naturally stronger than the previous two-piece lenses.

The new bi-colored fused lenses are beveled to fit spectacle goggles or cup-type goggles and are made in regular and 6-curve, round and FV3 shapes.

The following glass combinations are available: Cobalt-Clear; Noviweld-Clear; Calobar-Clear and Noviweld-Calobar in one-half and one-half combinations.

Transformer Welder

Air Reduction Sales Co., A Division of Air Reduction Co., Inc., has announced the availability of a new 200 amp. transformer welder.

The Airco 200-amp. Model MCX Transformer Welder is the latest development in the Wilson line. This small, compact (12 x 17 x 23 in. high) arc welder is designed to cover a wide range of applications from light duty sheet metal jobs to heavy duty industrial work.

The MCX has a full 200 amp., 50% duty cycle, N.E.M.A. rating. Three current ranges selected by insulated tapered plug connectors and infinite hand crank adjustments within each range provide currents from 30 to 250 amp. This permits the use of $^1/_{16}$-to $^3/_{16}$-in. diameter electrodes.

The Silicone insulation provides a high margin of safety two ways: it operates safely at high temperatures without breaking down and is water repellent.

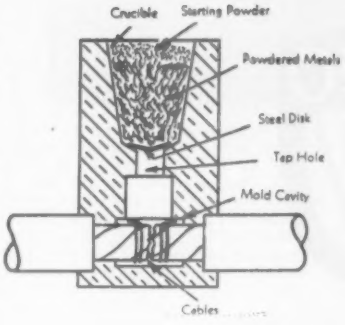
This welder employs an automatic hot-start control with a hermetically sealed gas-filled, time-delay relay magnetic switch that has no open contact. It is of simple construction to give efficient operation—there are no delicate relays, rectifiers, fuses or open arcing contacts.

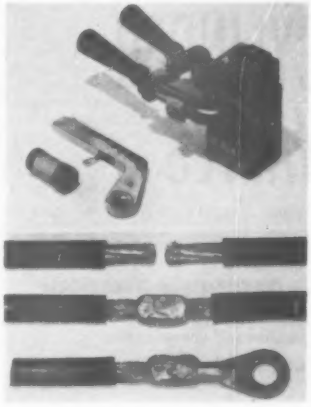
For further information about this new welder, write the Airco Sales office nearest you, or Air Reduction, 60 E. 42nd St., New York 17, N. Y.

Cable Connectors

The process is a method of welding copper to copper in which no outside source of heat is required. Powdered copper oxide and aluminum are dumped into a small graphite crucible and ignited by means of a spark. The molten copper flows over the cable ends in the graphite mold, these, too, becoming molten and, in a few seconds are securely welded together in a solid homogeneous copper nugget.

The procedure is first to prepare the cable by stripping approximately one inch of insulation from each end to be joined. Both ends are then placed in the welder, butted together under the center of tap hole and the clamp-type crucible locked. The flint spark gun ignites the mixture and in about 10 sec. the weld is completed. The same procedure and equipment would apply when attaching terminal lugs.





Advantages of the process claimed by the manufacturer are:

1. The joint is not damaged by excessive overload and is not subject to gradual loosening or oxidation.
2. It has greater current carrying capacity because it is a fusion weld of 98% copper and has a 50% greater cross section than the cable.
3. The splice is compact and permanent.
4. It is economical and easily made with inexpensive equipment.
5. It is fast. The time required to make a weld is less than one minute.

Welder available in two sizes. Model 263 handles 1/0 and 2/0 cable. Model 262 handles 3/0 and 4/0 cable. Erica Products, Inc., Cleveland 3, Ohio.

Small Welder

Model 25, 120-amp. welder manufactured by Precision Welder Mfg. Co., 5160–62 W. Homer St., Chicago 39, Ill., has been designed primarily to serve the farm, service station, small factory, homeowner and hobbyist.

It operates on 110- or 220-v. a.-c. current, giving six separate heats. The unit welds light and medium gage ferrous and nonferrous metals, including aluminum and brass and does brazing, soldering, heating, bending and other operations.

The case is made of 18 gage metal, finished in a heavy red crackle. The welder is sold complete with accessories as shown, which include one welding helmet, one ground clamp, one electrode holder and cable and a set of 26 electrodes. Over-all size is 14 in. long by 11½ in. wide by 10 in. high. Shipping weight 65 lb.

List price of welder and accessories complete is $75 and available to retailers, jobbers, distributors and factory representatives.

INTERESTING OPENING
WELDING RESEARCH

Opportunity to join our welding research staff is offered to a young, graduate welding engineer.

Excellent and better future in our constantly expanding organization.

Duties consist of formulating new procedures, testing alloys and fluxes, compiling technical papers.

Knowledge of all welding processes required.

Location, new plant in Flushing, N. Y.

Submit résumé to Rene Wasserman, President, Eutectic Welding Alloys Corporation, 40 Worth St., N. Y. C.

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REGO

HIGH PRESSURE
CYLINDER
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for OXYGEN and HYDROGEN

Designed, tested and proved for high pressures and severe service.

Packing may be replaced with cylinder under pressure if necessary.

Fuse plug and bursting disc provide positive safeguard.

Bronze stem furnished as standard, also available with monel stem on special order.

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Cadmium-plated steel stem with monel tip resists rust and wear.

Ball-nose seat construction assures positive shut-off.

for CARBON DIOXIDE

Available with diaphragm-type or packed-type construction.

Compact rugged design for use with high pressures.

Equipped with bursting disc safety device.

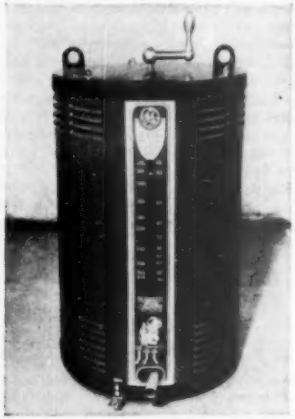
*Reg. U. S. Pat. Off.

The BASTIAN-BLESSING Co.
4201 West Peterson Ave. Chicago 30, Illinois

PIONEER AND LEADER IN THE DESIGN AND MANUFACTURE OF PRECISION EQUIPMENT FOR USING AND CONTROLLING HIGH PRESSURE GASES

G. E. Announces New Welder

A new silicone-insulated, portable, a.-c. welder, equipped with automatic "hot start" control has been announced by the Welding Divisions of General Electric's Apparatus Dept. Known as 6WK30J series, it is one of the first standard a.-c. welder lines commercially available incorporating silicone insulation. A high margin of safety and operating dependability is provided by this insulation since it is unaffected by high temperatures and is water repellent. The silicone used in this application is a product of the G-E Chemical Department, Pittsfield, Mass.



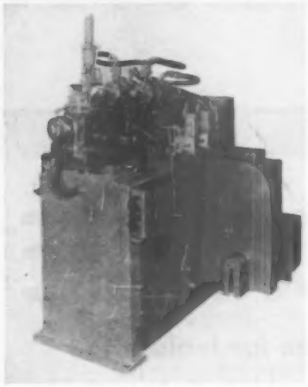
Instant arc striking without any manual adjustment is provided by "hot start" automatic control. The correct amount of boost is always furnished for any specific current setting. The ampere range is covered by three overlapping current ranges which permit precise current control. Thus with "hot start" control and overlapping current ranges, lower operating costs are assured because idling current is reduced to a minimum and more efficient use of electric power is accomplished.

The automatic "hot start" control—composed of a hermetically sealed gas-filled time-delay magnetic switch and a wound resistor—causes a surge of increased current to flow through the welding leads. This surge is present only during the critical starting period, and its degree is considerably higher at very low "hard-to-start" currents than at higher "easier-to-start" current settings. Automatic reduction of boost at higher current settings avoids drawing current surges from the power line. It is of simple construction to give trouble-free operation for it has no delicate relays, rectifiers, or fuses and is not affected by dust.

Compact construction—17 in. in diameter, and 35 in. in height—permits its utilization of underbench space not available to larger welding units. Averaging less than 1 lb. per ampere of maximum output the 6WK30J weighs 325 lb. and has a current range from 40 to 375 amp., and accommodates electrodes from $^{3}/_{32}$ to $^{1}/_{4}$ in. diameter. The welder can be used for welding light or heavy materials. Mounted on a running gear, it can be easily moved when required.

Series Spot Welder

The welder shown is designed to spot weld spouts to stainless steel coffee pots. This welder, with minor gear and cam alterations, is adaptable to welding many products other than coffee pots. These changes could permit spot spacing and electrode positioning on the outline of any curved surface within the maximum movement limitations of the equipment.



This welder is a special series spot welder equipped with one transformer for two welds. Spot spacing, work indexing and electrode operation are automatically controlled. Electrodes are always normal or perpendicular to the surface being welded.

The two pouring spouts are welded to two pots during one operation of the welder. Two watertight seams of 66 spots each, are made around the spouts in 20 sec. The external appearance of the 6-in. seam is so good that a minimum of polishing is required on this highly reflective surface.

The required unloading and reloading time is so short that one operator can service three welders. On this basis one operator and three welders can weld 770 spouts in one hour. For further information write to Taylor Winfield Corp.

New 1½-Ton, Battery-Powered Trammer

A new 1½-ton battery-powered trammer for use in mine-haulage work has been developed by the Locomotive and Car Equipment Divisions of the General Electric Co. Small and compact, but powerful, the trammer is designed for use in metal mines where clearances are restricted.

Available in any track gage between 18 and 24 in., the new unit is 71½ in. long over bumpers, 35⁹/₁₆ in. wide and weighs 3000 lb. with its battery. With a standard battery, the trammer is 38⅛ in. high; with a high-type battery, 44⅛ in. high. Individual drive from the motor to each of two axles provides maximum tractive effort.

The locomotive has a folding cab which permits loading in limited mine hoist cages. The frame is of rigid, all-welded construction from rolled carbon-steel plates. A turret mounted sealed beam headlight and a foot-operated warning gong are supplied with the trammer.

British Industries Announce 1951 Fair

Britain's annual industrial show, the British Industries Fair, will be held in 1951 from April 30th through May 11th. Heavy industry will be centered in Birmingham (England), and other trades will be on show in London in the biggest display in the Fair's 35-year history.

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EFFICIENT
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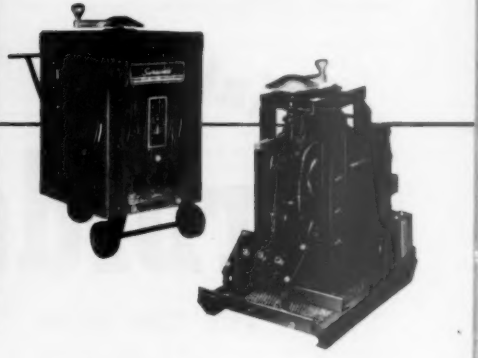
4 exclusive reasons why

Sureweld® is the BEST

COMPARE

Feature for feature the Sureweld A-C Arc Welder will surpass any other make . . .



9 INDUSTRIAL MODELS

5 SHOP MODELS

Model	NEMA Rating Amps.	Volts	Duty Cycle	Welding Range Min. Amps.	Welding Range Max. Amps.	Open Circuit Volts	*Open Circuit Voltage Reducer	Power Factor Correction
500RP	500	40	60%	25	700	80	Yes	Yes
500RPX	500	40	60%	25	700	80	No	Yes
400RP	400	40	60%	25	520	80	Yes	Yes
400RPX	400	40	60%	25	520	80	No	Yes
300RP	300	40	60%	25	450	80	Yes	Yes
300RPX	300	40	60%	25	450	80	No	Yes
200RP	200	40	60%	25	300	80	Yes	Yes
200RPX	200	40	60%	25	300	80	No	Yes
200RX	200	40	60%	25	300	80	No	No
30G	200	30	50%	25	260	75	No	No
30GP	200	30	50%	25	260	75	No	Yes
20G	150	30	50%	20	190	75	No	No
20GP	150	30	50%	20	190	75	No	Yes
10GP	180	25	20%	20	180	75	No	Yes

*Reduces open circuit to 40 volts when not welding.

WELDER YOU CAN BUY

No welder tops the Sureweld A-C Arc Welder for value! Dollar for dollar the Sureweld delivers *more* quality, *more* features, *more* solid performance.

You can *prove* it to yourself! Put the Sureweld into side-by-side competition with any other welder you can name—and watch Sureweld *out*-perform, *out*-economize, *out*-last the others.

Clip and mail the coupon below to get a free copy of the illustrated booklet, "New Era in Welding," giving *additional* reasons why Sureweld is *really* today's best buy! And if you'd like a demonstration, without obligation, put a check-mark, in the box.

NO OTHER WELDER HAS THIS UNIQUE 4-COIL TRANSFORMER

The "heart" of any welder is the transformer. The Sureweld's exclusive and different patented 4-coil transformer, with the movable shunt, gives the controlled power that means faster burn-off, proper penetration and correct breakdown of hard-to-handle alloy rods.

GUARANTEED—MADE TO NEMA SPECIFICATIONS

HIGHEST OPEN CIRCUIT VOLTAGE

Adequate open circuit voltage permits the ready use of heavy-coated, alloy and low-hydrogen electrodes, with ease in starting, ease in holding a steady arc. No other welder beats Sureweld's 80 volts. But personnel are safeguarded by a voltage reducer that automatically cuts current to 40 volts whenever the machine is not actually welding.

GREATEST TRANSFORMER CAPACITY

No welder can match Sureweld for extra pounds of copper and laminated iron. That's why Sureweld has *no fan*. There's enough transformer capacity to deliver peak output without overheating—yet *without* forced ventilation. No chance of the transformer burning out because of fan failure. This means extra long life for your Sureweld, and freedom from costly maintenance.

MOVABLE MAGNETIC SHUNT

Sureweld's exclusive and unique 4-coil transformer design with movable magnetic shunt gives *truly* stepless control, *really* smooth performance, and *uniformly* fine welding characteristics at all amperages. Movable shunt makes full-range control infinitely variable, and provides exact heat desired instantly at the turn of the handwheel.

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SECTION ACTIVITIES

Prepared by C. M. O'Leary

Anthony Wayne

An unusual dinner meeting was held on October 20th in the Fort Wayne Chamber of Commercial Building, Ft. Wayne, Ind. The American Steel Dredge Co. showed an entertaining, technicolor film on dredges in operation; suction dredges (all welded sectional). The dredges are in operation on the Schuylkill River in Pennsylvania and one in Indiana Lake, Ohio. A question and answer program with audience and experts participation was held with Judges George Laws, Arc; H. Hamilton, Gas; D. B. Rice, Laboratory, H. M. Johnson, Resistance. Cash prizes were awarded for the best answers.

Arizona

The October meeting of the Arizona section was held in the Aluminum Room of the Hotel Westward Ho on Wednesday, October 18th. Approximately 40 members and guests were present.

The meeting was presided over by Arthur Tesmer in the absence of the Chairman of the Section, James Johnson. Mr. Tesmer informed the Section that two members, Hal Savage and Gil Dye were the official Arizona delegates to the Metals Show in Chicago.

A very interesting and instructive talk was given by Hal Miller, Assistant Supervisor, Vocational and Agricultural Department, State of Arizona, who spoke on "Development of the Salt River Valley and the Importance of Welding Shops."

Another keenly interesting talk was given by Richard C. King on "Flying Saucers," which gave rise to considerable interested comment.

A Technicolor sound film, "Family in the Yukon" was shown through the courtesy of the Standard Oil Company of California.

Boston

The first meeting of the 1950–51 season of the Boston Section was held on October 9th in the Campus Room, Graduate House, M.I.T., Cambridge, with an attendance of 50 for dinner and 60 for the technical session. After dinner, a movie was shown, entitled "Crisis in Korea."

The technical speaker was Charles Bruno, Head of the Technical Service Department, Reynolds Metals Co. Mr. Bruno presented an interesting, clear cut talk on "Welding High Strength Aluminum Alloys." He also showed a movie on the construction of 61 ST Aluminum pipe line by Alabama Tennessee Seaboard Gas Co., which was very interesting.

Chattanooga

The first dinner meeting of the Chattanooga Section this year was held October 6th at the Maypole Restaurant, with 35 members and guests in attendance. Dinner was at 6:30 P.M. After dinner, preceding the technical session, a short football film was shown.

The speaker for the technical session was J. W. O'Neal, Jr., who is erection superintendent for the Converse Bridge & Steel Co. of Chattanooga. His topic was "Structural Erection Welding." Mr. O'Neal thoroughly discussed the types and usage of various rigging equipment necessary for field erection jobs when welding is employed. Also Mr. O'Neal compared the riveting and welding of structural steel and definitely concluded that welding results in lower costs. He stated that in his experience welding will save about one-third in labor costs alone. The Section thoroughly enjoyed Mr. O'Neal's speech and received much valuable information from him.

The November meeting of the Chattanooga Section was held on November 3 at the Maypole Restaurant in Chattanooga. Dinner was at 6:30 P.M. with 24 members and guests present. A "coffee hour" during which a short football movie was shown followed dinner.

The main business brought before the section was the Membership Drive. George Tepley, the Membership Committee Chairman, led the discussion and urged each member to do his part. Several prospects are already in sight.

The technical session was a discussion of the 1950 Metal Congress and Exposition, which was held in Chicago in October. Two members of the Chattanooga Section, Mr. Kelker and Mr. McClain, spoke at length on the impressions they received during their week at the Metal Show. Mr. Kelker outlined and commented on the technical papers which were read at the Metal Congress and Mr. McClain discussed the Exposition. After the discussion, a technical film on the control of distortion in arc welding was shown.

Cleveland

The first regular monthly meeting of the Cleveland Section was held on October 11th at the Allerton Hotel. This was a joint meeting with the Great Lakes Section of the Society of Naval Architects and Marine Engineers.

Attendance at the dinner was 65 members and guests, and at the meeting 92 members and guests.

Chairman J. C. Wyss opened the meeting. W. F. Stewart, Membership Chairman, introduced new A.W.S. members and told of the membership plans of his committee. R. J. Yarrow, Education and Plants Visit Chairman, announced the Cleveland Section sponsored 8-week course in "Fundamentals of Welding Metallurgy," will start in January, one night each week at Case Institute of Technology under Professor Jerry Cover.

Earl R. Hoover, Attorney and Lecturer, gave a very inspirational coffee talk on the history of our flag and national anthem. The circumstances leading up to the writing of the national anthem was vividly portrayed by a picture in words.

The technical speaker was Otis R. Carpenter, Director of Works Laboratory of the Babcock & Wilcox Co., Barberton, Ohio. Mr. Carpenter presented a paper on the subject "Welding and Fabrication of Marine Boilers."

The talk was well illustrated with slides and covered the construction of the conventional lake boat boilers, the victory ship and the newer type navy boilers for destroyers and cruisers. Steam conditions were in the range of 200 psi. and 50° SH. For comparison, stationary boilers were described.

Much of the welding is done with automatic submerged arc with welds up to 8 inches thick. However, extensive manual welding is also done requiring a force of 500 to 600 qualified welding operators.

The talk also covered the welding of austenitic and pearlitic steels. Mr. Carpenter's talk was followed by a barrage of questions from a round dozen of the audience, many with several questions.

The Section was pleased to have a welding engineer from England at this meeting. Peter Houldcraft of the British Welding Research Assn. is spending a year studying welding in this country. His work is entirely on welding research. He has been of invaluable service to the E.C.A. Cleveland Section members who worked with Mr. Houldcraft regard the exchange of information of great mutual value.

Colorado

After dinner at the Oxford Hotel, Denver, on October 10th, members and their guests met at the General Iron Works for a plant visit. They were taken on a tour of the entire plant which included the foundry, pattern shop, machine shop and plate shop. Many types of welding operations were viewed with interest and appreciation by all who attended.

Columbus

The Cooper-Bessemer Co. were hosts to the Columbus Section on Friday, October

13th. The members were broken up into groups and escorted through the various departments, foundry, pattern shop, core room, machine shop, assembly and weld shop. Each escort explained the operations as the group progressed.

The technical session opened with a dinner meeting. After dinner a brief intermission was called to regroup the members.

The meeting was called to order and reports of the various officers received. The highlight of the reports was the initiation of a membership drive. A $10 prize was offered for the member bringing in the most members between Oct. 13, 1950 and May 11, 1951. Membership application blanks were distributed so that the drive could get under way immediately.

R. Krieger, Technical Representative, reported a complete file of all A.W.S. publications available in his office.

R. F. Kymer showed slides of the various types of machines produced at Cooper-Bessemer, both welded and cast. He explained that although in most cases the weldment was more costly the end use warranted the extra cost of the welded unit. When an intricate part caused foundry trouble, redesign and welding was usually the answer to their problem. Mr. Kymer stated Cooper-Bessemer were the leaders in producing Nodular Iron for lighter castings. With the lighter weight of Nodular Iron and the ease of correcting stresses they have stayed with castings. He summed up his paper with the fact that usually they welded for small quantities and cast in larger quantities.

The A.W.S. members who favored welding strongly were active in questioning Mr. Kymer on some of his statement but he was able to answer most of their questions quite satisfactorily.

Cumberland Valley Division

Due to serious illness in his family, John Bert was unable to address the October 30th meeting of the Cumberland Valley Division, Maryland Section. Being the fine gentleman he is, his entire speech was made available for reading. However, upon good advance, and with the consent of all present, the talk was not read.

The dark cloud of disappointment for the meeting was dispersed by Dr. G. E. Claussen of the Reid-Avery Co., who accepted a telephone request for help.

Just like the school master and his pupils, the meeting progressed. One student, then another asking a question or making a statement, with the Professor always on top. Various topics were covered. Chicago meeting notes; A.W.S. Standards; Iron Show Exhibits; low-hydrogen electrodes, and their performance; inert arc, expansion and contraction. Everyone participated.

Dallas

Monthly meeting was held in the Auditorium of the Dallas Power and Light Co. on October 11th. Dinner preceded the meeting at Brockles Restaurant.

Ralph A. Trentham of Reed Engineering Co., Carthage, Mo., presented a clear-cut, illustrated talk on "New Tools for Metal Fabrication."

Refreshments were served after the meeting.

Dayton

October meeting was held on the 10th at the Engineers Club. Dinner was held in Suttmiller's Restaurant. After dinner there was a business meeting of the officers and board members.

Technical speaker was C. B. Voldrich of Battelle Memorial Institute, Columbus, Ohio. Mr. Voldrich spoke on the Weldability of Steels. Mr. Voldrich described the nature of cold cracking in the heat-affected base metal of metal arc welds in steels, and the influence of both steel properties and hydrogen from welding electrodes on the incidence of cold cracking.

Preceding the talk a film on the machining and welding of Magnesium was shown.

Any A.W.S. members who happen to be in Dayton the second Tuesday of the month are cordially invited to attend the Dayton meetings, which are held at the Engineers Club. Visitors are always welcome.

Detroit

Fifty-five members attended the dinner preceding the technical meeting on October 13th and, after dinner, listened to Danny Foster (famous racing boat driver of Silver Cup, Gold Cup and Harmsworth type boats). Mr. Foster recently won the Silver Cup Race at Detroit, and his comments regarding the development of power boat racing were most interesting.

The technical meeting, which was attended by 125 (33 of whom were guests), was on the subject of "Resistance Welding of Aluminum to Meet Aircraft ANW-30 Specifications." This subject was covered by two speakers: Dr. Clarence Bremer from the Chemical Research Dept., Oakite Products, Inc., who outlined the importance of cleaning in meeting ANW-30 specifications and also outlined the procedure to be used in obtaining the desired end; and J. F. Deffenbaugh who is with Federal Machine & Welder Co., outlined briefly the ANW-30 specifications and then made a comparison of the requirements for spot welding steel and aluminum. Considerable discussion followed, which bore out the fact that this is a very controversial subject. With the trend being toward War Work and, therefore, considerable expansion in the use of aluminum, this proved a very interesting and timely subject and was very well received.

Hartford

Dinner meeting of the Hartford Section was held on Thursday, October 12th at the Rockledge Country Club, West Hartford, Conn.

Robert Houle of the General Scientific Project Corporation, addressed the meeting on the subject "Pulse Wave Jet Engines."

Following the presentation, a movie "Telephone Courtesy" was shown and is recommended highly by the Section.

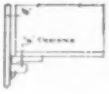
Houston

Dinner meeting of the Houston Section was held on October 12th at Ben Milam Hotel. Technical speaker was Ralph A. Trentham of The Reed Engineering Co. His subject was "New Tools for Fabrication."

Indiana

The September meeting was held on the 22nd at McClarney's Famous Restaurant, Indianapolis. Speaker at the technical meeting was E. C. Hurt of Haynes Stellite. His subject was "Hard Facing."

The October meeting held on the 20th



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was a dinner meeting as well as a tour of Plant 10 of the Delco Remy Plant; this is the Ignition Plant. The tour was very complete covering all processes of manufacturing.

Herman Hartzell, Asst. Chief Engineer of Delco Remy presented a discussion of the automotive ignition system. This was an excellent, extemporaneous, nontechnical talk.

Kansas City

A dinner party for members, wives and guests was held on Septmeber 21st at Fred Harvey's, Union Station.

Regular monthly meeting was held on October 19th at Fred Harvey's, Union Station. P. H. Smith presented an illustrated talk on "Alloy and Dissimilar Metal Fabrication." Mr. Smith used the slides to a good advantage when explaining his subject.

Lehigh Valley

Harry S. Collins, Eastern Regional Manager for the Metallizing Engineering Co., Inc., Long Island City, N. Y., was the guest speaker at the monthly meeting held on November 6th at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa. J. R. Fairhurst presided at the meeting.

Mr. Collins gave a talk on "The Metallizing Process and Its Practical Applications in Industry." He discussed the latest developments in the metal spraying gun to insure fool-proof operation, and outlined methods of applying flame-sprayed metal in order that a perfect bond with the base metal is assured. Mr. Collins' talk was illustrated with slides showing the many applications in practically all types of industries.

Following the technical session, there was a demonstration of the metallizing process. Seventy-five members and guests attended the meeting. A dinner meeting was held prior to the technical session at the Hotel Bethlehem, Bethlehem, Pa.

Los Angeles

A joint meeting of the Los Angeles Sections of the American Welding Society and the American Society of Mechanical Engineers was held on October 19th at the Rodger Young Auditorium. The meeting was attended by 123 members and guests of the two societies.

The program was divided into two parts covering the fabrication of alloy piping. J. J. Kanter, Directing Engineer of the Crane Company Research Laboratories, discussed selection of piping materials based on physical properties. E. R. Seabloom, Field Research Engineer for the Crane Co. described welding of alloy piping.

Mr. Kanter covered graphitization as related to various piping alloys and services. He presented interesting data on stress analysis and allowable temperatures for different piping materials. He discussed modern testing methods. Mr. Seabloom covered the welding of piping from the standpoint of joint design and the selection of welding alloys. Methods and procedures were presented.

The number of questions that followed the talks indicated the great interest generated on the subject of alloy piping.

Mahoning Valley

On September 21st the Mahoning Valley Section visited the plant of the General Motors Packard Electric Division at Warren, Ohio. This meeting was attended by approximately 50 members and guests and proved to be of great interest to all.

The making of electric cable of all descriptions from household extension cords to heavy water-cooled stranded cable was seen and examined with great interest.

On October 18th, the General American Transportation Corp.'s Sharon Division opened its doors for another plant visit.

The program chairman was H. B. Hunt, General Superintendent of the Plate-Welding Division of General American.

This plant visit was scheduled for 7:30 P.M. and was attended by 137 members and guests. It was one of the best turnouts this Section has ever had.

The members were conducted through the various departments of the plant by some of the foremen in the Plate-Welding Division who volunteered for such service. This visitation, particularly the welding of aluminum vessels for tank car fabrication, proved of great interest to everyone.

Following the plant visit, the members and guests went to the General American Foremen's new clubhouse for the business meeting.

The speakers on the program were W. G. Dixon, Welding Engineer of the American Welding and Mfg. Co., Warren, Ohio, who spoke on "The Fabrication of Stainless Steel by the Heliarc Process," and O. H. Kuhlke, Welding Engineer of General American Transportation Corp., who spoke on "Fabrication of Aluminum Tank Cars by the Inert-Gas Electric Welding, Heliarc, Manual and Automatic Processes."

After the business session, the members were served coffee and doughnuts, provided by General American.

Michiana

The Michiana Section enjoyed a very interesting trip through the Whirlpool Corp., St. Joseph, Mich., manufacturer of Whirlpool and Kenmore washers, ironers and dryers. About 40 members and guests made the tour through this, the world's largest maker of household washing machines.

Typical of the consumer goods industries, heavy reliance is made on spot and projection welding. One very unique operation is welding the legs to the bowl of the wringer type machines. This is a multiple projection weld, the projections being "scallops" on the edges of the legs formed when they are blanked from the sheet. Some thirty of these projections are placed against the outside of the bowl, and 3 pulses later, the legs are firmly attached.

The Section thanks Mr. Farrington and his guides for an interesting and instructive meeting.

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Milwaukee

The October meeting of the Milwaukee Section was held on the 20th at the Ambassador Hotel.

An interesting coffee talk on the activities of the F.B.I. was presented by J. H. Gassaway, a special agent in the Milwaukee office. Mr. Gassaway told about the accomplishments and work of the F.B.I.

The technical talk was presented by R. W. Murdock, Manager of Customer Engineering of the Nelson Stud Welding Co. The speaker developed the history of the origin of the stud welder in the ship yards for use first in studs for pipe hangers and electrical conduit supports as well as for securing wood decking. He then traced the spread of this tool to other industries. He explained how important the stud welder was in shipyard use during the war in saving man hours and reducing the need for trained welders in this type of work.

A short movie showing some modern applications of stud welding was followed by slides of some special applications.

Milwaukee plants were hosts to a party of 19 welding experts from England who were in the United States under the auspices of the Economic Cooperation Administration to see how welding is carried on in America. The party consisted of men from all branches of the welding industry, from welders to top management, and also the British Welding Research Association. Dr. Henry G. Taylor, Director of Research, of the above Association was in charge of the party. Two days were spent in visiting the A. O. Smith Co.'s plant, the Pressed Steel Tank Co. and the C. M. St. P. & P. R. R.

New Jersey

The regular monthly meeting of the New Jersey Section was held on October 17th at Essex House, Newark, N. J.

Just before the technical meeting an excellent film "Report from Tokyo" was shown through the courtesy of the Third Naval District, U. S. Navy Department.

Technical speaker was E. C. Hurt, Supervisor of Hard Facing Development, Haynes Stellite Co., Kokomo, Ind. Mr. Hurt's subject was "Hard Facing," and was illustrated with slides.

An after meeting social hour was held with the serving of coffee, beer and sandwiches.

The following Chairmen of Special Committees were introduced at the meeting by Chairman Walter Begerow.

Program—Ken Koopman, Linde Air Products Co.; *Membership*—John E. Gunning, Electric Arc, Inc.; *Advertising*—E. W. Evanson, Essex Welding & Equipment Co.; *Publicity*—Ford Pollock, Taylor Forge & Pipe Works; *Advisory*—Ken L. Walker, Foster Wheeler Corp.; *Educational*—George W. Nigh, Tidewater Associated Oil Co. and *Technical Representative*—F. C. Fyke, Standard Oil Development Co.

New York

The New York Section started its 1950–51 season with a meeting on October 10th, at which S. A. Wenk, Research Engineer, Battelle Memorial Institute, Columbus, Ohio, presented a paper on "Latest Developments in Testing and Inspection of Welds."

In his paper, Mr. Wenk pointed out that industry today was facing the same problems as confronted it ten years ago, and that in times of great productive activity proper inspection presented a major problem. Mr. Wenk stressed the importance of the correct interpretation of test results, and the value of correlating proved engineering experience and the required service life of the part with the results of inspection and test procedures.

Using slides to illustrate his talk, Mr. Wenk outlined the advances that have been made in recent years in inspection methods. The methods of inspection by means of ultrasonic techniques, magnetic particles and X-rays were covered in Mr. Wenk's paper. In addition, he described in detail a new inspection method developed at Battelle Memorial Institute, known as Xero-Radiography, which in essence is a low cost X-ray technique.

J. Bland, Senior Welding Engineer, New York Naval Shipyard, capably served as the Technical Chairman of the meeting. Arrangements for the meeting were made by H. R. Clauser, 1st Vice-Chairman and A. M. Setapen, 2nd Vice-Chairman and Program Chairman.

Preceding the technical session, dinner was held at Schwartz's Restaurant, 54 Broad St., New York, where all meetings for the 1950–51 season will take place. Following dinner, a motion picture entitled, "Highlights in the World Series" was presented through the courtesy of the New York Yankee Baseball Club.

The meeting was well attended, and the New York Section was pleased to welcome many members of the SOCIETY for Nondestructive Testing to this meeting.

Philadelphia

The October meeting held on the 16th, continued the interesting and high caliber meetings for which the Philadelphia Section is noted.

R. J. Erffe, Vice-President, Northwestern National Bank, in his coffee talk on "To What Extent Can a Bank Help a Small Business," gave an interesting discussion of banks and banking. His analysis of the banking problems encountered in business was helpful to everyone present.

David L. Mathias, Research Engineer, Arc Rods Corp., brought members up to date on electrode developments in his talk, "What's New in the Field of Arc Welding Electrodes." The importance of this subject is driven home when we remember that most of our present electrodes are of recent enough development to be called new. Yet the changes and developments continue at a relentless pace. Mr. Mathias could not predict the changes and advances that will be forthcoming in such a rapidly moving field. The interest in this subject was apparent by the informal discussion that continued long after the close of the formal meeting.

The panel discussion meetings are continuing their well-earned popularity from last year. On Friday, Nov. 3, 1950 over 110 members and guests came to learn the answers on "Welding Stabilized Stainless Steels." The shortage of columbium and the necessity of substituting other stabilizing agents has spotlighted this problem. The answers to the problem were supplied in able fashion by the panel members, Alan J. Rosenburg Thomson Laboratory General Electric Co.; George A. Sands, Electro Metallurgical Division, Union Carbide and Carbon Corp.; D. Carl Buch, Carnegie-Illinois Steel Corp. and J. H. McConnell with R. David Thomas Jr., as the moderator.

"Fabrication of High-Temperature, High-Pressure Steam Piping," which was one of the popular topics at last year's panel discussion meetings, will be the subject of our January meeting. This joint meeting with the Philadelphia Section of the Society of Naval Architects and Marine Engineers will help us keep abreast of the latest developments in alloy piping for both stationary and ship applications.

Pittsburgh

The October 18th meeting was held in the Auditorium of Mellon Institute of Industrial Research. Dinner preceded the meeting at the Hotel Webster Hall.

Mr. F. E. Garriott, Manager, Weldrod Department, Ampco Metal, Inc., Milwaukee, discussed the use of bronze electrodes in general. Mr. Garriott also showed a film "Golden Horizons," which with his discussion provided a very complete evening for the members and guests.

Portland

Twenty-one members and guests attended the first fall session in the Elk's Club Lower Private Dining Room, held on September 12th.

After the dinner hour the meeting was called to order at 8:00 P.M. by Chairman Chas. J. Daniels, Willamette Iron and Steel Co. After the reading and approval of the minutes of the preceding meeting, Chairman Daniels announced the appointments of the following committees:

Technical Committee: James T. Gow, *Chairman* (Electric Steel & Foundry Co.); A. A. Robley (Asst. Prof., Oregon State College); H. A. Sanner (Hyster Co.); J. H. Crumley (King Bros., Inc.) and L. E. Poole (Consulting Engineer).

Membership Committee: T. R. Williams, *Chairman* (J. E. Haseltine & Co.).

Program Committee: E. H. Weil, *Chairman* (Lincoln Electric Co.).

Those present were urged to suggest the types of meetings most desired to assure attendance at future meetings. After a group discussion on program material the subject of "How to Increase Membership" was actively discussed.

This being the first meeting of the year, the program was of an informal nature. No speakers were called upon. However, E. H. Weil, *Program Committee Chairman*

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sponsored the showing of two movie films. The first was shown through the courtesy of the Gardner-Denver Co. and was on the subject of Pipelining. It was entitled "As The Crow Flies." The second film was entitled "Football Sport Parade" and was shown through the courtesy of the Associated Oil Co.

The meeting was adjourned at 9:30 P.M.

Rochester

The members of the Rochester Section were guests of Delco Appliance Division of General Motors for a plant visit on October 16th. Howard Jones, Works Manager, greeted the large turnout of about 120 members and propsective members. A good roast beef dinner in the plant cafeteria, compliments of Delco, through arrangements by William Blackman, was enjoyed by all.

The plant tour was conducted by 14 very capable guides. A very efficient setup for the production of oil burners and gas furnace space heating units was shown. The company is utilizing some of the latest type equipment in the fabricating field, such as spot, seam projection and arc welding, to produce a highly competitive item.

This trip showed the important place welding has attained in mass production industries.

The Rochester Section extends thanks and appreciation to Delco for a very enjoyable and interesting evening.

St. Louis

Dinner meeting of the St. Louis Section was held on October 13th at Forest Park Hotel.

A film "National Air Races" was shown through the courtesy of the U. S. Rubber Co.

The subject "Design and Construction Advantages Considered in Welding a Large St. Louis Structure" was presented by C. S. Johnson, Jr., Engineer, Sverdrup & Parcel, Consulting Engineers. This was a very timely subject inasmuch as the St. Louis Building Codes do not condone the welding of major connections and Mr. Johnson presented details of how these and other restrictions were overcome.

Susquehanna Valley

The November 8th dinner meeting of the Susquehanna Valley Section was held at the Hotel Sterling, Wilkesbarre, Pa. Dinner speaker was A. G. Leake, who spoke on Welding Experience and Pioneering in the Welding Field.

Dr. H. C. Campbell, Associate Research Director, Arcos Corp., was the technical speaker. His subject was on "Metallurgy for the Welder."

Both talks were well received.

A film on the History of Tool Steel Forming of Aluminum was also enjoyed.

Following the technical session there was a business meeting with active interest.

Tulsa

The Tulsa Section conducted an electrode school on October 23-26 in Tulsa at the Tulsa University. This school was conducted by E. B. Lutes, Production Manager of the Arcrods Corp., Sparrows Point, Md. Two hundred and seventy-five persons attended. At the time tickets for this electrode school were sold at the rate of $4.00 for the 4-nights' course, an affiliate membership for an additional $1.00 or a total of $5.00 for the electrode course and an affiliate membership card. This program was well received.

A tape recording of the entire school is available through the Tulsa Section Secretary to anyone interested.

Washington, D. C.

The September 29th meeting was held at Engineers Club of Washington, Inc. Lew Gilbert, Editor of *Industry and Welding* gave an interesting, clear-cut talk on "Trained Operators Produce Better, More Economical Welding." A question period on the practical problems of the operator and operator problems of the management followed.

Wichita

On October 9th the Wichita Section met at the Coleman Mfg. Co., North Plant. E. A. Bussard of the Coleman Mfg. Co. gave an excellent talk on Copper Furnace Brazing. Slides showing the Modern Methods of Furnace Brazing were also shown.

An inspection tour of the Coleman Mfg. Co. copper brazing furnaces was also made.

Worcester

The October 25th meeting of the Worcester Section was held at the Tower House with 70 members and guests present.

Following the dinner, Program Chairman William Walker introduced the speaker of the evening, Roger J. Metzler, Development Engineer from Handy and Harman of New York. Mr. Metzler first showed a very interesting movie in color, showing the methods and uses of silver alloy brazing in modern industry.

Following the picture, Mr. Metzler delivered a very instructive and informative talk on "Low-Temperature Silver Alloy Brazing." He pointed out the six fundamental steps for the successful application of low-temperature brazing as follows: proper fit-up; clean metal; proper fluxing; proper assembly and supporting of material; correct heating and flowing of alloy; proper cleaning of residual oxides.

A movie on Stock Car Racing followed the meeting, and was enjoyed very much by those present.

Employment Service Bulletin

Position Vacant

V-248. Welding Metallurgist. Aluminum manufacturer located in Northwest has an attractive position as Laboratory Technician in Research Laboratory for a recent graduate with undergraduate work in welding. Practical experience would be desirable but not mandatory. Please enclose recent photograph as well as details of education and salary requirements.

V-249. Welding Machine Salesman. Opportunity to join sales staff of leading long established firm in arc welding industry as Specialist in Welding Machine Sales. Job includes liaison with factory on design and production, and working with national sales organization of direct salesmen and distributors in building sales of complete line A.-C., D.-C., and Inert-Arc Welders. Location Chicago. Write, giving personal data, qualifications, salary required, etc.

Services Available

A-611. Metallurgical and Welding Engineer. Graduate B.S. 1940, M.S. in Eng. 1951 Jan. Experienced in Welding since 1933 on Arc and Gas, Automatic Arc, Submerged and Inert Gas, Spot and Seam Welding Sales Engineering High Alloy and Stainless Steel by all methods. Will consider opening in California, Washington, Oregon, Texas and Oklahoma. Registered Professional Engineer.

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WELDING JOURNAL

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,523,291—Electric Welding Fixture—Gilbert Gilliver, London, England, Assignor to International Standard Electric Corp., New York, N. Y., a corporation of Delaware.

Gilliver's patent relates to a fixture for electrically welding a bead tip to a metal article and the fixture includes a metal stand having an electrically nonconducting top portion with a recess portion therein. A metallic spring member forms a connection between the metal stand and a metal article placed in the recessed portion thereof for fixedly holding the article in such recess. Additional means provide an electric conductor from the metal stand to a source of electric current.

2,523,367—Swivel Type Spot Welding Electrode—Edman F. Holt, Indianapolis, Ind., assignor to P. R. Mallory & Co., Inc., Indianapolis, Ind., a corporation of Delaware.

This patent is on an electrode which has a cap portion, having a working face and an inside face, and a main body portion. A ball is formed on the main body portion of the electrode and it mates with the inside face of the cap portion. The cap portion is maintained on the electrode body portion by pressure means and slideably moves on the ball of the electrode. Bore means penetrate the ball to provide a path for coolant means to flow into direct contact with the inside face of the cap portion to cool same.

2,524,098—Attachment Unit for Acetylene Torches—Nils H. Christenson, Wyoming, Ohio.

A trammeler attachment unit is provided for an acetylene torch, and is attachable thereto. The attachment includes a pair of arms that are pivotally secured together at one end of the arm, a rod holder pivotally connected to the free end of each arm, and means for securing rods carried by the rod holder in adjusted position to the rod holding means. The clamp means on one of the rods are provided to attach the unit to a torch.

2,524,223—Arc Oxygen Cutting Accessory—Fred J. Girous, Hartford, Conn.

This patented accessory is for use with an electrode holder. The accessory includes a manually controlled valve connected to a source of oxygen supply, and clamping means connecting with the valve to attach the accessory to an insulating handle of the electrode positioning means. An adapter head is connected to the valve to receive oxygen therefrom and it includes an apertured resilient body for fitting on the end portion of a hollow electrode to supply oxygen to same.

2,524,257—Engine Control for Electric Welding Machine—Charles J. Harrah, Denver, Colo.

This patent relates to a combination circuit-closing device and throttle opening device for engine driven, electric welding generators.

2,524,369—Method of Electric Flash Welding Cylindrical Members and Product Thereof—Julius B. Tiedemann, Milwaukee, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

This special welding method includes forming an annular circumferential flange on the outside of a cylindrical metal block, disposing insulating material in the crevice between the flange and the body of the block, and forcing the flange inwardly to a position parallel to the outer surface of the body of the block to fold such flange over at least a portion of the electrically insulating material. Then a tubular skirt member is electrically butt welded to the outer edge of the flange by a circumferential joint disposed radially outwardly from the body of the block and the insulating material prevents flow of welding current between the body of the skirt except for the flange area of such block.

2,524,730—Controlling Device for Gas Torches—Charles D. Lawhon, Stratford, Conn., assignor to Robertshaw-Fulton Controls Co., Bridgeport, Conn., a corporation of Delaware.

The patented control device for gas torches includes a valve device which is carried by a flexible wall that is hermetically sealed in a chamber to divide it into two parts. A thrust rod cooperates with the valve member and a lever is pivotally mounted on the device and controls the thrust rod. The lever provides the support by which the torch may be suspended and is movable under the weight of the torch to actuate the thrust rod and control the valve member.

2,524,969—Welder's Work Holder—Charles F. Fairchild, Fulton, Mo.

This patent covers a very specialized work holder that includes a flat web with four arms integral with the web and extending radially outwardly of the edges thereof in the plane of the web at 90° intervals. Other specialized means are associated with the flat web member.

2,525,055 — Heating and Hardening Burner—Bert G. Ward, Jr., Chicago, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Deleware.

Ward's burner is designed to produce a plurality of high temperature heating flames and includes an elongated metal body that has a single manifold passage therein extending lengthwise thereof and a row of branch passages leading from the manifold passage to outlets in the face of the burner body. The metal body also has a plurality of grooves formed in opposite sides thereof located between pairs of the outlets formed therein. Plates are secured to opposite sides of the burner body and cover only a part of the length of the groove adjacent the face of the burner to define open-ended passages terminating at the face adjacent to and between pairs of the outlets for the combustible gas mixture provided.

2,525,241—Attachment for Acetylene Cutting Torches—Walter F. Rentsch, San Francisco, Calif.

The patented attachment for a cutting torch includes a torch-gripping clamp with a support shaft and gear means connected thereto. A support-contacting drive wheel is provided for engagement with a supporting surface to position the attachment and a cutting torch associated therewith with relation to such support surface. Rotation of the support wheel provides rotation of the gear means provided depending upon movement of the torch unit with relation to the support surface provided.

2,525,657—Method of Electric Arc Welding—Isaac M. Diller, Glen Ridge, N. J.

Diller's patented welding method relates to the welding of varying thickness members by a continuous welding operation. The method comprises feeding a welding rod of varying mass per unit length toward the weld path at a definite feed rate as the members are moved along the weld path at a definite speed of travel and the feed rate and speed are so related that mass variation of the weld rod becomes greater or less substantially in consonance with the respectively greater or lesser thickness of the members moving relative thereto and being welded thereby

2,525,852—Composite Weld Rod—Ludovico Morlon Barbe-Boujours, Vigo-Espineiro, Spain.

This patent covers an arc-welding electrode wherein a center electrode rod is provided and has a pair of longitudinal sleeves of heat-insulating and electrical-insulating material positioned there-around with a metallic helix being positioned between the two sleeves. The outer sleeve is fusible at a higher temperature than the inner sleeve to maintain the outer sleeve temporarily unfused at the arc-forming tip of the rod after the center electrode rod and inner sleeve are fused.

2,525,862—Electrical Resistance Butt Welding Apparatus—Otis R. Carpenter, Barberton, George J. Hartnett, Jr., Wadsworth and Reidar P. C. Rasmusen, Akron, Ohio, assignors to The Babcock & Wilcox Co., Rockleigh, N. J., a corporation of New Jersey.

In this butt welding apparatus, a fixed clamping means and a movable clamping means are provided for positioning a pair of metal workpieces in longitudinal alignment. Additional means are provided for facing the end of the workpieces and the movable clamping means can be advanced toward the fixed clamping means to position the ends of the workpieces in juxtaposition for welding action. A special machining head is provided for preparing the ends of the workpieces for welding action.

2,525,875 — Apparatus for Thermochemically Cutting Metal—George M. Deming, Orange, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

Deming's apparatus includes a torch having a tip provided with a cutting-oxygen passage and an oxygen supply conduit in communication with such tip passage. An injector is provided and the oxygen passes through it on the way to the tip passage whereas a fuel-gas supply conduit also connects to the injector. Special valve means are provided whereby oxygen can pass through the injector and draw in fuel-gas to produce a large flame jet, or the valve can be positioned so that oxygen alone is delivered to the tip passage.

2,526,035—Welding Apparatus—Kenneth H. Miller, Chicago, Ill. assignor to Mid-States Equipment Co., a corporation of Illinois.

This welding gun is provided to deposit and peen metallic material onto metallic objects. The metallic electrode is carried by a body member and means in the body member are provided for vibrating the electrode into and out of engagement with the object for intermittently making and breaking the welding arc to deposit metallic material intermittently, and simultaneously peen the metallic material deposited on the object.

2,526,423—Apparatus and Method for Cutting Materials — Dagobert William Rudorff, London, England.

This patented apparatus is provided for cutting electrically conductive materials and it includes a cutter member having a cutting edge maintained in a predetermined close relation to the metal to be removed from the workpiece. An electric circuit is provided and includes the cutter member and the workpiece while a source of direct current supply is connected so that the cutter member is of negative polarity and the circuit is adjusted so that electric oscillation and a spark discharge are continuously produced at the cutting edge of the cutter member. Additional means provide a fluid flow through the cutting zone to remove therefrom particles of material disintegrated from the workpiece and to keep the cutting zone continuously cooled.

LIST OF NEW MEMBERS

October 1 to October 31, 1950

ATLANTA

Filbert, J. L. (C)

BIRMINGHAM

Bottomley, W. H., Jr. (C)
Nickell, K. V. (C)
Scheibner, Carl F. (C)

BOSTON

French, Everett (C)
Horgan, Bryan (C)
Janosky, Walter C. (C)
McKeon, Edward J. (C)
Pantano, John (C)
Peterson, W. L. (B)
Sinton, Robert (B)

BRIDGEPORT

Blomquist, Harold V. (B)

CHATTANOOGA

Marshall, William (C)

CHICAGO

Berner, W. A. (B)
Christopher, Goerge C. (B)
Farrell, William J. (B)
McMillan, Howard (B)

CLEVELAND

Capron, H. R. (C)

COLUMBUS

Evans, Irwin William (D)
Kearns, William H. (B)
Marshall, Finley (C)
Monroe, Robert E. (B)
Pittinger, Paul J. (C)
Tepper, John J. (C)

DALLAS

Nosh, Cecil E. (C)
Rountree, D. D. (C)

DETROIT

Abrams, C. D. (C)
Alexander, William G. (B)
Boucher, A. F. (B)
Collett, Harold (B)
Hill, Alec J. (B)
Kassel, Glen (C)
Lemon, J. W. (B)
Lohrer, Walter R. (D)
Michalek, Steve M. (C)
Seltzer, Clifford S. (B)
Stanchus, Frank T. (B)
Strong, J. M. (C)

HOUSTON

Demecs, Steven R. (B)
Greer, Eldridge V. (C)
Kennedy, A. E. (C)
Merritt, R. A. (C)
Raymond, G. (B)

INDIANA

Reiss, Paul R. (B)

INLAND EMPIRE

Wrigley, James B. (B)

KANSAS CITY

Nichols, Sam (C)

LEHIGH VALLEY

Rapp, William G. (C)
Zahm, William W. (C)

LONG BEACH

Ghio, William Anthony (B)
Pryor, Jack (C)

LOUISVILLE

Conyers, John D. (C)

MAHONING VALLEY

Pickup, Carter H. (B)
Ryan, Charles (C)

MARYLAND

McKee, Richard J. (C)
Stymiest, George E. (C)

MICHIANA

Boggs, Myrl Martin (C)

MILWAUKEE

Hiller, Austin (C)
Hinkley, Frederick Eugene (C)

NEW JERSEY

Johnsen, William K. (B)

NEW YORK

Carter, William R. (C)
Francis, Don E. (C)
Franklin, Bernard R. (C)
Smith, Spencer Gray (C)

NIAGARA FRONTIER

Hayhurst, George V. (B)
Newton, Ralph C. (B)

NORTHERN NEW YORK

Glasbrenner, Frederick K. (C)
Huber, Henry J. (C)

NORTHWEST

Qualey, Norman C. (B)

NORTHWESTERN PA.

Hagans, Robert R. (D)
Johnson, Harold A. (C)
Karnes, M. Richard (D)
McClure, W. C., Jr. (B)
Riley, John M. (C)
Thomas, John F. (C)

OKLAHOMA CITY

Burggraf, C. T. (C)
Dawson, Jim (D)

PEORIA

Barra, Joseph M. (C)
Wynkoop, Clyde (C)

PHILADELPHIA

Berckman, Glenn K. (C)
Koby, George (B)
McCormick, Charlton P. (C)
Petry, Phillip C. (C)
Roe, Walter G. (C)
Seeburger, John E. (C)
Thompson, J. S. (C)

PITTSBURGH

Brown, Alexander C., Jr. (B)
Kelly, Bernard J. (C)
Komarnitsky, R. S. (B)
Kramer, Lloyd B. (C)

PORTLAND

May, Anthony (B)
Powers, Hurschel A. (B)

PUGET SOUND

Stobbart, W. M. (C)

ROCHESTER

Avery, Richard E. (C)
Woodhall, Harold (C)

SAGINAW VALLEY

Sargent, Robert L. (C)
Springer, Jack B. (D)

ST. LOUIS

Royer, Russell A. (B)

SUSQUEHANNA VALLEY

Clarke, Stanley, Jr. (C)
Holden, Roy J., Jr., (C)
Scott, E. Reid (C)

TRI-STATE

Roehm, C. J. (C)

TULSA

Hill, A. M. (B)
Wainwright, R. H. (B)

WASHINGTON

Snyder, Paul E. (C)

WESTERN MASS.

DeMarco, John P. (B)

WESTERN MICHIGAN

Bracken, Darwin H. (B)
Budrick, John C. (C)
Hall, Robert W. (C)
Hansen, Christian W. (C)
Smith, W. E. (C)
Stoutjesdyk, John (C)
Szezepaniuk, John (C)

WORCESTER

Evans, John T., Jr. (B)
Gale, Conrad E. (C)
Holmes, Ralph Herbert (B)

YORK-CENTRAL PA.

Boettger, Charles Edward (C)

NOT IN SECTIONS

Johnson, O. Knox (C)
Knox, David Black (B)
Magnusson, Erik Jeppe (B)
Potter, Robert (D)
Simonek, Jaroslav (B)
Takagi, Otomaru (B)
Torres, Felix A. (B)

Members Reclassified

CHICAGO

Seid, Howard R. (C to B)

DETROIT

Bennewitz, Robert H. (C to B)
Clark, Roy L. (C to B)
Hawks, B. R. (C to B)
Weaver, Jess E. (C to B)

KANSAS CITY

Payne, Joseph M. (C to B)

NEW YORK

Brown, David (B to A)

PITTSBURGH

Davis, Claude E. (C to B)

Final 1949-50 Board of Directors Meeting

(Continued from page 1116)

powered to act for the Board of Directors in the administration of the affairs of the SOCIETY as may be necessary from time to time between meetings of the Board of Directors. Action taken by the Executive Committee shall be subject to approval by the Board of Directors at their next regular meeting."

Activity at Shreveport, La.

The Secretary reported that there is activity underway for the formation of an A.W.S. section at Shreveport, La. An activation committee has been formed and the outlook is encouraging.

Future Meetings of Board of Directors

In addition to holding a meeting of the Board in the city where the 1951 Annual Meeting will take place, namely, Detroit, the Board members were in favor of holding a meeting, during the 1950-51 administrative year, in Boston but left the time and place for such meetings to be determined by the President.

It was suggested that a meeting of the Board be held in Boston the early part of February.

In that the A.W.S. Detroit Section will hold its last spring meeting on Friday evening, May 11, 1951, the Board favored this date for their meeting in Detroit so that they could attend the Detroit Section's meeting in addition to the Board meeting.

West Coast Activities

Prof. G. S. Schaller advised of the forthcoming Western Metal Congress and Exposition in Oakland, Calif., Mar. 19-23, 1951. He extended a cordial invitation to all Officers and Board members of the SOCIETY to visit the West Coast at that time. He pointed out that the West Coast and Northwest particularly, being remote from the East Coast, did not feel as close a part of the SOCIETY as they should and the situation would be improved if the SOCIETY's Officers and Headquarters Staff visit the West Coast more frequently. He observed the difficulty the West Coast Sections have in securing speakers and urged that the National Society assist the West Coast Sections in working up a program for the technical meetings, particularly during the Western Metal Congress and Exposition activity.

Expression of Appreciation Extended to Retiring President

The Board extended a vote of thanks to retiring President O. B. J. Fraser for his diligent efforts and untiring performance while in office as President and also as acting President during the illness of Past-President G. N. Sieger. Mr. Sieger and the Secretary were authorized to prepare a letter acknowledging the SOCIETY's indebtedness and to transmit to Mr. Fraser.

Time and Place of Next Meeting

The next meeting of the Board of Directors was set for the early part of December and to take place in New York City.

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WELDING RESEARCH COUNCIL

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Supplement to The Welding Journal, December, 1950

Physical Metallurgy of Austenitic Stainless Steels

A review of the present state of knowledge and of the results of recent research investigations on the subject of Cr-Ni stainless steels and their weldability which highlight phase relations, corrosion resistance, crack sensitivity, stress-corrosion cracking and the effects of cold deformation and of subzero and elevated temperatures

by Helmut Thielsch

SUMMARY

PUBLISHED and unpublished data and developments made during the past decade are reviewed, analyzed, and interpreted. The physical, metallurgical, and welding characteristics of the various austenitic chromium-nickel stainless steel types are discussed with reference to their fabricating and service behavior.

The many superior properties which are offered by the austenitic stainless steels, particularly in applications at elevated temperatures or in corrosive environments, have been proved by the great use that is made of these alloys. This review discusses the major characteristics of commercial and experimental compositions and highlights the difficulties that are occasionally experienced.

Helmut Thielsch is Technical Assistant, Welding Research Council, New York, N. Y.

This report was prepared under the auspices of the Literature Advisory Committee of the Welding Research Council. G. E. Doan, *Chairman*; T. S. Fuller; L. E. Grinter; C. E. Jackson; E. M. MacCutcheon; W. Spraragen; David Swan; R. David Thomas, Jr.; J. L. Walmsley and Helmut Thielsch, *Secretary*.

Many chromium-nickel types of stainless steels are not fully austenitic, but may also contain varying quantities of the ferrite, sigma, and carbide phases. The actual phases or compounds which may be present depend upon (1) composition, (2) heat treatment, (3) time of exposure at elevated temperatures, and (4) effects of cold deformation. In addition the structure of castings and weld deposits is affected by solidification rates. It is important, however, to realize that, although some of these phases can be developed in stainless steels on exposure to certain appropriate temperatures, it is not implied that these phases exist in many of the stainless steels as furnished by the supplier.

The amount of ferrite that can be expected in wrought grades and in weld deposits can be predicted from Figs. 3 and 4, respectively. The presence of small amounts of ferrite is particularly important in 18–8 (Cr-Ni) weld deposits. Its presence in the deposit inhibits crack sensitivity. On the other hand, small amounts of ferrite are generally believed to reduce somewhat the corrosion resistance of steels exposed to certain highly corrosive conditions. Thus, in a few solutions the use of fully austenitic structures may be necessary, although partially ferritic, molybdenum-bearing 18–8 (Cr-Ni) stainless steels are extensively and satisfactorily used. Moreover, the cold-fabricat-

ing characteristics of stable austenitic steels are superior, when deformation is severe, to those in which transformation to ferrite occurs during cold working.

The sigma phase increases hardness and strength and considerably decreases the ductility and toughness of stainless steels. Thus, adjustment of composition may be necessary to prevent sigma formation between 1050 and 1700° F. (565 and 925° C.). Moreover, if sigma has formed it can be removed by a suitable heat-treatment before the stainless steel goes into service.

Precipitation of chromium carbides at the grain boundaries greatly reduces intergranular-corrosion resistance and may somewhat lower the impact toughness of steels exposed for long periods between 1100 and 1500° F. (595 and 815° C.).

Intergranular corrosion may be prevented or reduced by several methods: (1) a full anneal above 1850° F. (1010° C.) followed by rapid cooling, (2) an immunizing heat treatment between 1350 and 1550° F. (730 and 845° C.), (3) the presence of ferrite, (4) the use of *extra-low carbon* grades containing less than 0.03% carbon, and (5) the use of stabilizing elements such as columbium, titanium, etc.

Weld-metal cracking generally can be traced to the action of six major factors: (1) microstructure, (2) composition of the electrode and of the parent metal of the steel, (3) welding technique, (4) electrode coating, (5) geometry of weld, and (6) the degree of restraint.

The susceptibility of stainless steels to stress-corrosion cracking is determined by (1) stresses in the steel, (2) the action of the corroding agent, (3) plastic deformation of the steel, (4) the physical characteristics of the alloy, and (5) the time of exposure in the corroding solution.

When metastable austenitic compositions are cold worked, some of the austenite tends to transform into ferrite.* The amount of ferrite that forms depends upon (1) the degree of deformation, (2) temperature, (3) composition, and (4) rate of deformation. The rate of deformation generally is closely related to temperature.

Cold deformation also increases tensile and yield strengths and reduces ductility and toughness. In fabricating operations intermittent annealing treatments at different stages of the cold-forming process may be necessary to prevent breakage in the stainless steel or in the forming tools.

Quenching of wrought and cast stainless steels may introduce residual stresses of considerable magnitude. However, their removal may not be necessary. Only in the isolated cases in which stress-corrosion cracking would give concern, may relief of residual-tension stresses in the surface be desirable.

For service at elevated temperatures the use of fully austenitic compositions is generally desirable if maximum hot strength is wanted. However, where maximum protection against unexpected or unpredictable stresses is required, the partially ferritic grades may have an advantage. The desire to produce partially ferritic 18–8 (Cr-Ni) weld deposits, which are thereby less sensitive to hot cracking, is an example of the benefits of the presence of small quantities of ferrite.

Creep strength and stress-to-rupture properties are improved by the presence of finely distributed particles in the austenite matrix. Typical values for wrought stainless steels and weld deposits are given in Tables 15 to 18. A steel with a coarse grain size will exhibit superior creep strength and stress-to-rupture properties over a steel with similar composition but a fine grain size.

* Actually an acicular (pseudomartensitic) type of ferrite supersaturated with carbon will form on transformations of the austenite below 400° F. (205° C.). Although its lattice is that of α-ferrite, it is harder than the austenitic matrix.

INTRODUCTION

The selection of a particular grade of stainless steel is based upon several considerations: economy, manufacturing and fabricating characteristics, and service requirements.

On the one hand it is desirable to select the least expensive grade of steel. However, fabricating operations may introduce limitations which require the use of one of the many special types. For example, severe cold-forming operations are best performed with stainless steels containing a fully austenitic structure. Similarly, the final applications and service requirements of the fabricated structures and equipment may determine the selection of a particular steel grade. Thus, corrosion-resisting characteristics are highly important. If the steel is used at elevated temperatures, metallurgical characteristics such as sigma formation must be considered. Welding procedures introduce additional variables.

The various factors which may have a bearing upon the selection and characteristics of stainless steel types are discussed from the point of view of their metallurgy. When it is necessary, supporting data are presented in tabular or graphical form.

When it is applicable, differentiation is also made between wrought steels, weld metal, and cast stainless steels. Since the heat-resistant, cast stainless types have a higher carbon content, they differ somewhat in a number of their characteristics from corresponding wrought stainless steel grades and weld metal.

METASTABLE AUSTENITE

In recent years because of the efforts of research investigators, the manufacturers and fabricators of austenite-stainless steels have become more and more cognizant of the fact that the stability and properties of the austenite depend on various factors.

In the common wrought stainless steels (up to 0.20% carbon) any austenite which is retained after a quenching treatment from 1700° F. (925° C.) is present because of extreme sluggishness; i.e., it is metastable. The three-component equilibrium diagram for these quenched alloys, as reported by Bain and Aborn,[39] is shown in Fig. 1.

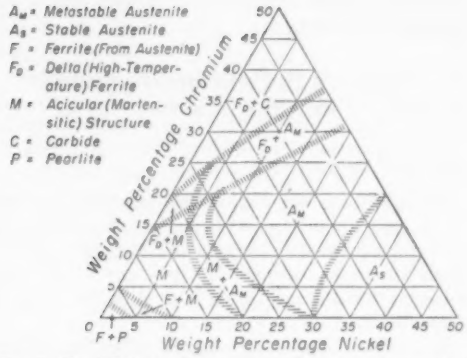


Fig. 1 Equilibrium diagram of chromium-iron-nickel system showing phases after rapid cooling from temperatures of maximum austenite at a carbon content of 0.1%[39]

The heat-resistant types of cast stainless steels generally contain more carbon than wrought stainless grades having corresponding amounts of chromium and nickel. The higher carbon content is likely to shift the point of maximum austenite stability to temperatures above 1800° F. (980° C.). Moreover, slight variations in the equilibrium relations make differentiation between the common wrought grades and the heat-resistant cast grades advisable. Figure 2 presents the equilibrium relations for the latter alloys which contain about 0.4% carbon, 1.2% silicon, and 0.8% manganese. These cast alloys had been heated for 100 hr. at 1800° F. (980° C.) and furnace cooled.[249]

Exposure at subzero temperatures may cause some transformation into ferrite. Heat treatments in the intermediate range may affect the precipitation of carbides and the formation of the sigma phase. Cold work may also initiate or enhance the formation of ferrite and/or of the sigma phase.

Moreover, although slight variations in the amount of the two major elements, chromium and nickel, may produce considerable changes, more pronounced effects may be caused by many of the minor alloying elements and by impurities. Thus it may at times be found incorrect to assume that a certain type of stainless steel of a chemical analysis on the low side of the specified range will behave in an identical manner with the same type of steel on the high side of the specified composition range. This is one of the reasons why specification ranges are being constantly narrowed down and subdivided.

From a commercial viewpoint the effects of many minor alloying elements and impurities are more correctly appraised by statistical studies of production heats than by singular investigations that may incorrectly highlight the fact that a slight difference in composition or the presence of certain minor alloying elements are the reasons for a difference in behavior. This often leads to the development of specifications which are unnecessarily restrictive. Producers, consequently, find themselves confronted with numerous proprietary specifications, many of which are unnecessarily limiting and conflicting.

In many cases a fully austenitic structure may seem most desirable. In other instances more favorable properties are introduced by the presence of secondary phases, particularly ferrite. These factors are discussed in subsequent sections.

When secondary phases or compounds are present in the austenite matrix, they are usually distributed as fine particles along the grain boundaries—unless considerable quantities and suitable heat treatments cause their agglomeration into larger particles. Thus in wrought alloys ferrite, when it is present, often occurs in the form of striated or lens-shaped regions. In weld deposits and in castings because of coring,* which is due to dendritic solidification, the tendency to precipitate secondary phases is greater than if a wrought (homogenized) alloy of identical composition had been quenched from temperatures between 1700 and 2350° F. (925 and 1290° C.). For this reason castings may show as much as 15 to 20% more ferrite than a quench-annealed wrought alloy. Moreover, the secondary phases are well dispersed and appear in the dendritic pattern, which is typical of castings and weld deposits, and in the grain boundaries.

Microscopically it may be quite difficult to distinguish accurately between the precipitated compounds or phases. Thus, it is likely that much of the confusion about the effects of sigma, ferrite, carbides, and other possible structural components is caused by mistaken identification. Also, there are critical sizes and distributions which cause maximum corrosion pitting or maximum or minimum values in one or several of the physical characteristics; e.g., impact, tensile, and other properties. For a particular composition the compounds and phases that form depend upon the previous history of the material, the heat treatment, and the time at the respective elevated temperature.

* Variable composition in solid-solution dendrites. The center of the dendrite is richer in one element, as shown by the pertinent solidus-liquidus lines in the phase diagram (*Metals Handbook*).[39]

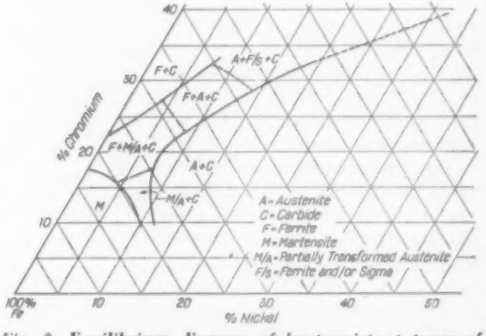


Fig. 2 Equilibrium diagram of heat-resistant types of chromium-iron-nickel alloys aged 100 hr. at 1800° F. (980° C.) and slowly cooled. Alloys contain about 0.04% C, 1.2% Si and 0.8% Mn[249]

EFFECTS OF COMPOSITION

The presence of major and minor elements in the chromium-nickel stainless steels makes accurate predictions of the structure approaching equilibrium quite difficult, i.e., the amount of austenite which should be present as the result of a particular annealing (or homogenizing) heat treatment. Carbon, nitrogen, nickel, and to lesser degrees manganese, copper, and cobalt are credited with a widening of the austenite region, i.e., they act as *austenite formers* or *austenitizers*. On the other hand chromium, tungsten, tantalum, molybdenum, columbium, and particularly silicon, titanium, vanadium, and aluminum are credited with supporting the formation of ferrite at elevated temperatures. These elements, therefore, are called *ferrite formers* or *ferritizers*. Consequently, if a fully austenitic steel with a low-carbon content is desired, either the amount of one or more of the other austenitizers present has to be increased or the quantity of a ferritizer, present in the steel, has to be decreased.

Some of the elements which promote the formation of ferrite at elevated temperatures may stabilize austenite by causing sluggishness toward transformation at low temperatures and, as such, may indirectly act as austenite stabilizers. Chromium seems to be an example of such an element.

The whole picture is complicated by the tendency of columbium, titanium, tantalum, chromium, and certain other elements to form carbides which reduces their ability to act as ferritizers. On the other hand carbide formation may be prevented by reducing the quantity of free carbon, the most effective austenite former. Nitrogen, which acts in a manner similar to carbon, must also be considered. Various other particles may also form and, thus, increase the difficulties of deriving accurate interpretations.

In addition to a high-chromium content (generally above 20%) the presence of nickel, molybdenum, silicon, columbium, titanium, and other elements is recognized as promoting the formation of the sigma phase in these austenitic steels during exposure to certain favorable temperatures.

Unfortunately the role played by each individual element is not absolute. Thus, it would be incorrect to assume that by doubling the amount of a particular element it would act twice as powerfully either as an austenitizer or as a ferritizer.

These many variables make interpretations difficult. Careful analysis of all these factors is important before the metallurgy of the austenitic chromium-nickel stainless steels can be fully appreciated. This is particularly true in the case of welding where additional considerations have to be made because the cast nature of the weld deposit tends to produce cored structures. These variables will be dealt with in the subsequent sections.

FERRITE IN CHROMIUM-NICKEL STAINLESS STEELS

Effects of Composition

The structural constituents* which may be expected in wrought, quench-annealed, chromium-nickel steels were first predicted by Strauss and Maurer.[24] Subsequent studies by Scherer, Riedrich and Hoch[25] and Schaeffler[66] resulted in the modified structural diagram shown in Fig. 3.

As the various alloying elements affect the amount of ferrite which may form from the austenite, various investigators have proposed empirical equations to predict the structural composition. Thus, for wrought materials a formula developed by Newell and Fleischman[42] was modified by Post and Eberly[54] and takes the form:

$$Ni = \frac{(Cr + 1.5\,Mo - 20)^2}{12} - \frac{Mn}{2} - 35\,C + 15$$

This equation was believed valid for the following range of composition:

	%
C	0.03– 0.20
Mn	0.4 – 4.0
Si	0.30– 0.50
Cr	14 –25
Ni	7.5 –21
Mo	Nil – 3

If the amount of nickel present in the alloy exceeds the summation of the elements on the right side of the equation, the homogenized alloy could be expected to be fully austenitic. The equation was found useful in predicting the suitability of stainless alloys for use in certain severe hot-forming operations, which are per-

* Microstructures, in which both ferrite and austenite are present, generally are called "duplex structures" and have also been called "unbalanced structures."

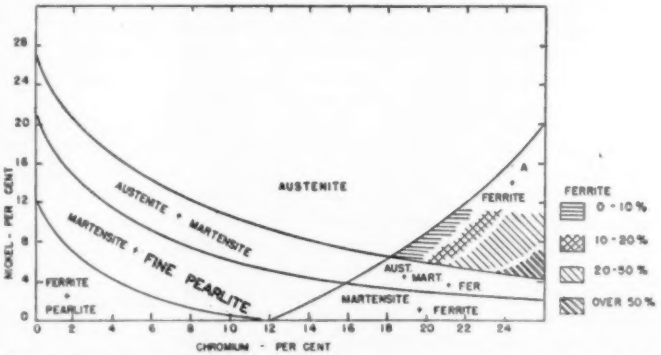


Fig. 3 Structural diagram of wrought quench-annealed chromium-nickel steels after E. Maurer. Region from 17 to 26% Cr and 3 to 11% Ni verified by Scherer-Riedrich-Hoch for 0.07 to 0.13% C, 0.30 to 0.48% Mn and 0.23 to 0.37% Si (after Schaeffler[66])

formed best with fully austenitic compositions. Similar equations have been proposed by other investigators.[21]

Weld deposits or castings, because of coring, will contain a greater amount of ferrite than the quench-annealed (homogenized) wrought alloys. Thus, various investigators,[21, 29, 45, 55, 66, 188, 210] recognizing this important fact, suggested changes in some of the constants. For weld deposits the equation* may be written as:[248]

$$Ni = 1.1\,(Cr + Mo + 1.5\,Si + 0.5\,Cb) - \frac{Mn}{2} - 30\,C - 8.2$$

A corresponding structural diagram developed by Schaeffler[29] is shown in Fig. 4.

In Table 1 the various equivalent values for chromium and nickel as proposed by different investigators are summarized. The elements do not have absolute equivalent factors. Instead, the magnitude of their ferrite- or austenite-forming tendency is a function of the ma-

* Based on Fig. 4.

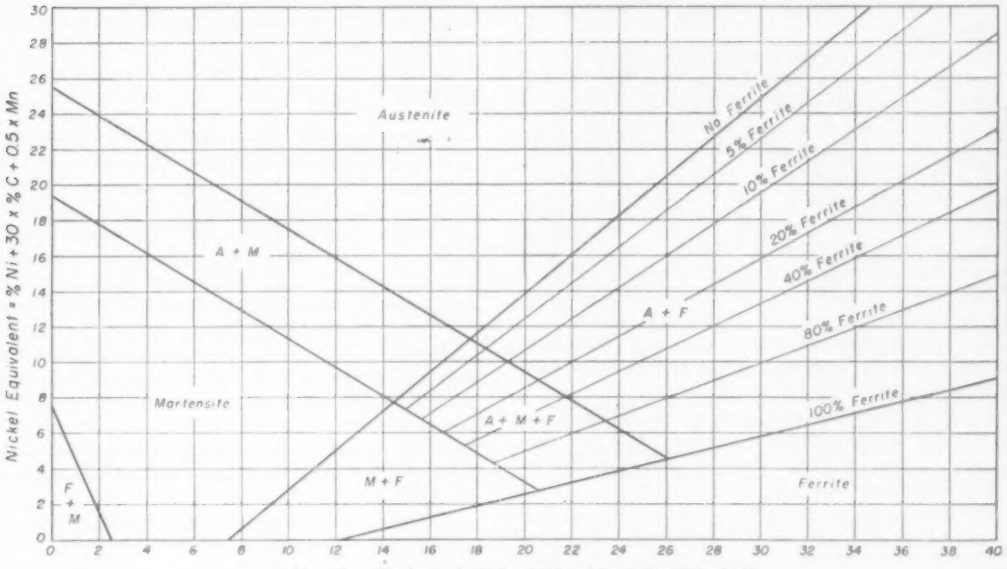


Fig. 4 Structural diagram for stainless steel weld metal (Schaeffler[29])

Table 1—Comparison of Equivalent Values for Chromium and Nickel as Proposed by Various Authors (Chromium and Nickel Are Written as Unity)

Investigators →	Thielemann[62]	Newell and Fleischman[42]	Post and Eberly[64]	Binder, Brown and Franks[21]	Avery[210]	Feild, Bloom and Linnert[188]	Campbell and Thomas[21]	Henry, Claussen and Linnert[61]	Schaeffler[29]
State of material →	Wrought chromium stainless grades	Wrought 18–12 stainless grades	Wrought Cr-Ni stainless grades	Wrought Cr-Ni stainless grades	Cast heat-resistant stainless grades	20–10 weld metal	25–20 weld metal	Cr-Ni weld metal	Cr-Ni weld metal
Austenite-forming elements									
Carbon	13	30	35	30	17	30	...	30	30
Nitrogen	...	...	...	26	11	...	...	...	...
Nickel	1	1	1	1	1	1	...	1	1
Manganese	0.7	0.5	0.5	...	...	0.5	...	0.5	0.5
Copper	0.3	...	...	...	...	...	...	...	...
Cobalt	...	...	...	...	...	...	...	...	...
Ferrite-forming elements									
Aluminum	12	...	...	...	...	...	...	...	...
Vanadium	11	...	...	...	...	...	...	...	...
Titanium	7.2	...	...	...	...	...	...	5	...
Silicon	5.2	...	...	...	1.6	...	...	1	1.5
Columbium	4.5	...	...	...	2.8	...	2	2	0.5
Molybdenum	4.2	2	1.5	2.25	...	2	1.5	2	1
Tantalum	2.8	...	...	...	...	...	...	...	...
Tungsten	2.1	...	...	...	...	...	...	...	...
Chromium	1	1	1	1	1	1	1	1	1

jor elements, chromium and nickel, and the interaction among the various minor alloying elements. This was indicated in data by Franks, Binder, and Bishop[3] who investigated the microstructures of molybdenum- and columbium-bearing 18–8 (Cr-Ni) stainless grades and found that the "free" or uncombined percentages of each element affect the ferrite content in the austenitic matrix. Changes in solubility of the minor alloying elements in the ferritic or austenitic matrix should also be considered.

Effects of Temperature

Temperature also has some bearing on the amount of ferrite present.

On exposure between 750 and 1470° F. (400 and 800° C.) some of the retained austenite tends to break down into ferrite and carbides. The actual amounts are a function of temperature, time, and composition. For example, in the metastable 18–8 (Cr-Ni) and more highly alloyed compositions such heat treatments may cause noticeable effects when temperatures above 1000° F. (540° C.) are reached. Thus, on exposure at around 1200° F. (650° C.) a 21–9 (Cr-Ni), heat-resistant casting may show ferrite development which is particularly evident in creep tests.[209] Similar consideration should hold true in type 18–8 (Cr-Ni) weld metal.

In the fully austenitic alloys, these heat treatments may not have any noticeable effects other than the possible appearance of precipitated carbides.

However, when some of the austenite transforms into ferrite and carbides, internal stresses will be set up. These result in decreased ductility and toughness,[14] which in some instances may be deleterious.

In several chromium-nickel alloys strong ferrite formers such as aluminum and/or titanium are purposely added in sufficient quantities to cause the complete transformation of the metastable austenite to a low-carbon, acicular ferrite. In these alloys the action of strong ferritizers changes the stability of the austenite so that on cooling the transformation occurs in a measurable period of time at temperatures even lower than 750° F. (400° C.). The "stress-laden" ferrite which forms at or slightly above room temperature during cooling from austenitizing temperatures* is particularly useful in some of the age-hardening stainless steels in which it may appear.[3, 67, 164]

Heating the metastable austenitic steels at successively higher temperatures above 1600° F. (870° C.) will also increase the amount of (delta) ferrite.[25, 26] Thus, when heat treating cast 26–12 (Cr-Ni) alloys, Avery, Cook, and Fellows[92] obtained maximum ferrite development at 2000° F. (1095° C.). In wrought, columbium-bearing 19–9 (Cr-Ni) grades Wylie[26] also observed an increase in ferrite up to approximately 2250° F. (1230° C.), at which temperature he noticed a sudden decrease in the amount of ferrite that had formed. Similar results were observed by Rollason[217] on 19–9-Cb (Cr-Ni-Cb) alloys which showed a sudden decrease in the ferrite content at temperatures somewhat above 2250 to 2370° F. (1230 to 1300° C.). However, as the temperatures were raised still further, the amount of ferrite rapidly increased again.

It might be suggested here that the decrease in ferrite content after a maximum amount had formed is caused by the solution of carbides, which allows the "free" carbon to become active as an austenitizer. In 18–8 or 26–12 (Cr-Ni) steels chromium carbides begin to dissolve above 2000° F. (1095° C.).† Columbium carbides, which are more stable than chromium carbides, probably begin to dissolve at temperatures above 2250° F. (1230° C.). However, once the carbides have been dissolved, ferrite may again form, as was observed by Rollason.

Effects of Welding

Electrode size also has some effect on the amount of (delta) ferrite that may form in weld deposits. This is obvious when changes occur in the composition of the weld deposit. Such changes may be caused by slight differences in the oxidizing and slag-forming characteristics of large and small diameter electrodes since they do not transfer equal quantities of the alloying elements from the electrode to the weld deposit. However, since the structural analysis of weld deposits is based upon the chemical composition of the weld deposit and not the electrode, the welding characteristics of the electrode do not have to be considered. Of course, the chemical analysis should include such elements as nitrogen which may have been absorbed from the atmosphere and which, as a strong austenite former,[2] increases the total austenite content.

Typical data on the effects of electrode size are given in Table 2.[61] Generally, electrodes with larger diameters produce deposits containing more ferrite on welding plates of equal thickness than do electrodes with smaller diameters. It may appear that the slower rates of solidification of the weld metal deposited by the heavier $^3/_{16}$-in. electrodes are responsible for the higher ferrite content. However, it is more than likely that the difference in ferrite content is due to the amount of carbon deposited, which varies with the size of the electrode employed, rather than the rate of solidification. Thus, the results of welding experiments made on preheated and on water-quenched plates revealed no noticeable differences in the amounts of ferrite even though there were wide variations in the rate of cooling.[217]

Effects of Physical Properties

In most compositions the presence of some ferrite well dispersed in the austenite matrix is thought to be beneficial in reducing the crack sensitivity of weld deposits. Moreover the yield point[106] and tensile strength[20] are raised considerably by the presence of ferrite.

* The temperatures at which the steel tends to form austenite by transformation of ferrite to austenite.

† See also Fig. 11.

Table 2—Weld-Test Data for 20-10 (Cr-Ni) Electrodes, Influence of Electrode Size on Microstructure[61]

Heat	Electrode size, in.	Material	Composition C	Mn	Si	Cr	Ni	Delta ferrite in austenitic matrix of weld structure: Amount	Approximate percentage
A		Core wire	0.058	1.60	0.21	20.37	11.12	....	....
	3/16	Weld metal	0.061	1.22	0.16	19.58	11.51	Very small	Less than 1/2
	5/32	Weld metal	0.073	1.16	0.16	19.35	11.51	Trace	....
B		Core wire	0.063	1.87	0.37	20.21	10.85	....	....
	3/16	Weld metal	0.063	1.28	0.22	19.70	11.07	Small	1
	5/32	Weld metal	0.064	1.30	0.20	19.58	11.04	Trace	....
C		Core wire	0.055	1.93	0.40	20.59	10.93	....	....
	3/16	Weld metal	0.064	1.47	0.28	20.08	10.98	Moderate	4
	3/32	Weld metal	0.062	1.40	0.25	19.96	11.02	Moderate	4
D		Core wire	0.060	1.83	0.36	20.48	10.87	....	....
	3/16	Weld metal	0.063	1.45	0.27	19.93	10.97	Moderate	5
	3/32	Weld metal	0.083	1.44	0.24	19.80	11.04	Small	1
E		Core wire	0.054	1.63	0.51	20.07	9.23	....	....
	3/16	Weld metal	0.066	1.28	0.41	19.40	9.25	Large	10
	3/32	Weld metal	0.070	1.25	0.38	19.32	9.36	Moderate	4

In Table 3 the effects of heat treatment on the room-temperature tensile properties of partially ferritic columbium-bearing 19-9 (Cr-Ni) weld metal are given.[100] The increased tensile and yield strengths which result from heat treatments between 1250 and 1450° F. (675 and 790° C.) may well be due to the earlier mentioned fact that in this temperature range a maximum amount of ferrite tends to form. In addition the presence of finely distributed carbide and (possibly) sigma particles may add to the increase in yield and tensile strength. Above 1450° F. (790° C.) some of the ferrite is likely to transform into austenite. Moreover, the carbide and sigma particles, if present, are likely to coagulate and grow in size. These changes tend to decrease tensile and yield strength values.

The effects of ferrite content on the mechanical properties at room temperature and at 1200° F. (650° C.) of weld deposits of similar compositions are illustrated in Table 4.[253] It is apparent that the presence of ferrite increases yield and tensile strengths at room and elevated temperatures. The stress-to-rupture values, on the other hand, are decreased. Creep strength would also be decreased. The effects of ferrite on the elevated-temperature properties are discussed in detail on pages 615-618.

The presence of ferrite also introduces a number of disadvantages. Thus, the cold-working and hot-working characteristics of fully austenitic compositions are superior to those with partially ferritic compositions. For example, the presence of ferrite considerably reduces pierceability at elevated temperatures.[145] Consequently, fully austenitic stainless steels are generally used when the steels are to be pierced by the rotary process.[46] At elevated temperatures the stress-to-rupture properties also are reduced when appreciable amounts of ferrite are present.

At room temperature a number of cold-forming processes also are detrimentally affected by the presence of ferrite.

PRESENCE OF SIGMA IN STAINLESS STEELS*

In addition to ferrite and austenite a third phase may appear in the Cr-Ni alloys. This phase, designated as sigma, exhibits a distorted complex tetragonal space-lattice which is highly brittle. Because when originally discovered sigma contained almost equal amounts of iron and chromium, the phase was labeled FeCr. Other elements may be soluble in the sigma phase. For example, nickel is believed to be soluble in sigma in amounts approaching 10%.

In the austenitic stainless steels sigma may form on exposing the alloys between 1050 and 1700° F. (565 and 925° C.). However, this temperature range may be somewhat modified by the presence of various alloying elements.

Chromium-Iron-Nickel Composition

In chromium-iron-nickel alloys changes toward equilibrium between 1050 and 1700° F. (565 and 925°

* See also references 7, 26, 58, 98.

Table 3—Effects of Heat Treatments on the Room-Temperature Tensile Properties of a Partially Ferritic Stainless Weld Metal[100]

Heat treatment	Tensile strength, psi.	Yield point, psi.	Elongation, %	Reduction in area, %
	19-9-Cb (Cr-Ni-Cb) Containing About 10% Ferrite			
As-welded	97,000	71,500	32.0	49.8
1250° F.—20 hr.—air cooled	102,180	73,980	26.0	43.8
1350° F.—20 hr.—air cooled	106,500	72,500	23.0	33.1
1450° F.—20 hr.—air cooled	104,000	68,000	25.0	34.0
1550° F.—20 hr.—air cooled	96,760	58,660	29.0	46.7
1650° F.—20 hr.—air cooled	90,700	54,570	34.0	55.0

Table 4—Effects of Ferrite Content on the Mechanical Properties of Weld Metal in the As-Welded Condition[253]

No.	Type	Estimated ferrite, % (1)	Composition								
			C	Mn	Si	S	P	Cr	Ni	Mo	Cb
1	316 Austenite	0	0.06	1.89	0.51	0.009	0.018	18.51	13.45	2.25	...
2	316 Austenite + ferrite	5.7	0.05	1.80	0.60	0.008	0.018	20.56	12.55	2.20	...
3	318 Austenite	0	0.07	1.86	0.20	0.010	0.022	17.01	13.41	2.13	0.71
4	318 Austenite + ferrite	0.6	0.07	1.88	0.73	0.016	0.029	18.84	12.62	2.06	0.68
5	347 Austenite	1.0	0.07	1.39	0.59	0.011	0.012	19.90	11.73	...	0.76
6	347 Austenite + ferrite	8.3	0.06	1.79	0.69	0.013	0.026	20.22	9.64	...	0.93

			Room temperature				1200° F. (650° C.)				
									Stress-to-rupture values, psi.		
No.	Type	Estimated ferrite, % (1)	Yield strength, psi.	Tensile strength, psi.	Elongation in 2 in., %	R. A., %	Tensile strength, psi.	Elongation in 2 in., %	10 hr.	100 hr.	1000 hr.
1	316 Austenite	0	58,000	82,000	41	55	46,000	26	31,000	24,000	
2	316 Austenite + ferrite	5.7	67,000	88,000	41	51	47,000	23	37,000	25,000	
3	318 Austenite	0	62,000	82,000	28	34	56,000	15	43,000	38,000	34,000
4	318 Austenite + ferrite	0.6	67,000	90,000	33	48	58,000	22	48,000	38,000	30,000
5	347 Austenite	1.0	66,000	88,000	33 (2)	50	51,000	16	44,000	36,000	
6	347 Austenite + ferrite	8.3	74,000	100,000	30	49	53,000	17	42,000	28,000	

(1) Estimated with Aminco-Brenner Magne-Gage. (2) Elongation in 1 in.

C.) occur at very slow rates. Thus Rees, Burns, and Cook[103] were not convinced that equilibrium conditions were reached in alloys heated for periods up to 100 or 200 days at 1200 and 1470° F. (650 and 800° C.). There is a decrease in the transformation rates to sigma when the temperature is lowered. This increased sluggishness may explain why sigma is rarely found in austenitic stainless steels which are used at temperatures below 1050° F. (565° C.). Moreover, in a number of austenitic stainless steels sigma does not form.

Equilibrium relations of chromium-iron-nickel alloys were first shown by Schafmeister and Ergang[19] at a temperature of 1200° F. (650° C.). Subsequently, Bradley and Goldschmidt[14] developed a similar diagram for alloys heated at 1650° F. (900° C.). The results of very thorough studies on extremely pure alloys were published recently by Rees, Burns, and Cook.[103]† The equilibrium diagrams shown in Figs. 5 and 6 are based on the work of these investigators.*

The differences in the equilibrium boundaries reported by the above authors are principally due to the presence of minor alloying elements. However, testing temperature and time of exposure at the respective temperatures are also important factors. Moreover, slight differences in the phase boundaries are noted even between determinations made from X-ray and microscopic observations.[103]

The relative positions of a number of the common Cr-Ni stainless steels have been indicated in Figs. 5 and 6. However, it should be remembered that the phase limits are shifted by most of the alloying elements present in these steels. Thus, many of the borderline compositions may never exhibit sigma formation even on long-time service exposures between 1050 and 1700° F. (565 and 925° C.). Of course, it is extremely unlikely that the 15-35 (Cr-Ni) compositions lying deeply in the austenite region of the equilibrium diagram will ever become embrittled by sigma precipitation.[183]

Effects of Structure

In alloys containing some ferrite dispersed in the austenite matrix, sigma seems to form preferentially from the ferrite. Four major factors are believed to be responsible for this.[33, 208] They are: (1) the crystallographic structure of ferrite resembles that of sigma more closely than does the structure of austenite, (2) atomic mobility is greater in ferrite than in austenite, (3) the preferential precipitation of carbides in the ferrite sites concentrates the alloying elements locally or distorts the ferrite lattice and thereby facilitates the formation of sigma, and (4) the segregation of chromium in ferrite in preference to austenite tends to produce ferrite areas which are considerably higher in chromium than normal alloy composition would indicate. However, duplex compositions exposed for lengthy periods at precipitation temperatures may also show highly dispersed sigma particles in the austenite matrix.[102]

In many borderline compositions in which the tendency for sigma formation is not too strong, transformation rates of sigma directly from austenite appear to be extremely small, if not negligible. In fact in many austenitic alloys sigma precipitation seems to be preceded by a precipitation of fine alpha particles, which for higher nickel compositions seem quite persistent.[103] However, most investigators feel that direct

* Present studies in several research laboratories indicate that sigma may form at a still lower chromium content than has previously been recognized and is shown in Figs. 5 and 6.

† Additional studies by Pugh and Nisbet[259] are based on incomplete (too short) heat treatments which did not reach equilibrium conditions.[254, 255, 256]

transformation from austenite into sigma is possible, particularly when the tendency for sigma formation is high. Such conditions exist in austenitic alloys containing 25% chromium or at lower chromium levels when molybdenum or silicon are also present.[3, 8, 20, 33, 40, 47, 49, 53, 132, 197, 227, 238]

Since in fully austenitic steels sigma precipitation is almost invariably associated with carbides, Foley[213] and Dulis and Smith[227] suggested that the alloyed carbides act as nuclei for the formation of sigma. Thus, it may be speculated[213] that the high-chromium content needed for sigma formation may be obtained from the chromium-rich carbide particles. Molybdenum and silicon would enhance this action. Moreover, it may well be that, when molybdenum is present, $(Cr\ Mo)_2C$ particles would form first and sigma forms afterward by taking the chromium and molybdenum from the carbide. New carbides could then be formed when additional chromium and molybdenum enter the area by diffusion.

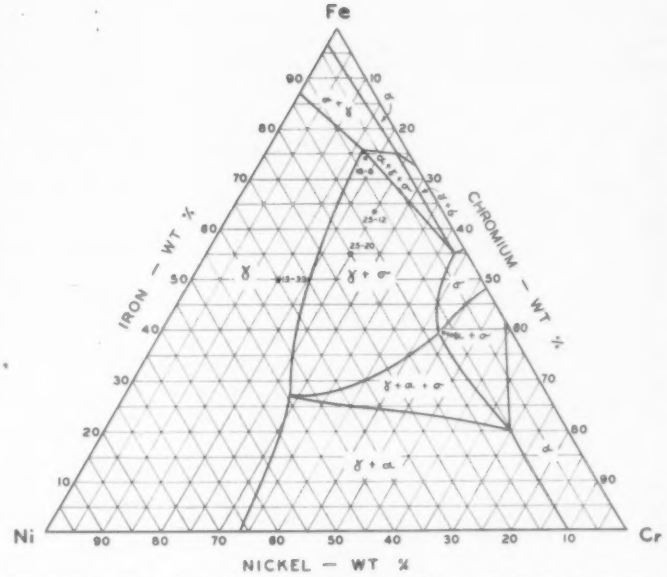


Fig. 5 Iron-chromium-nickel phase diagram at 1200° F. (650° C.) (after references 19, 44, 103, 200)

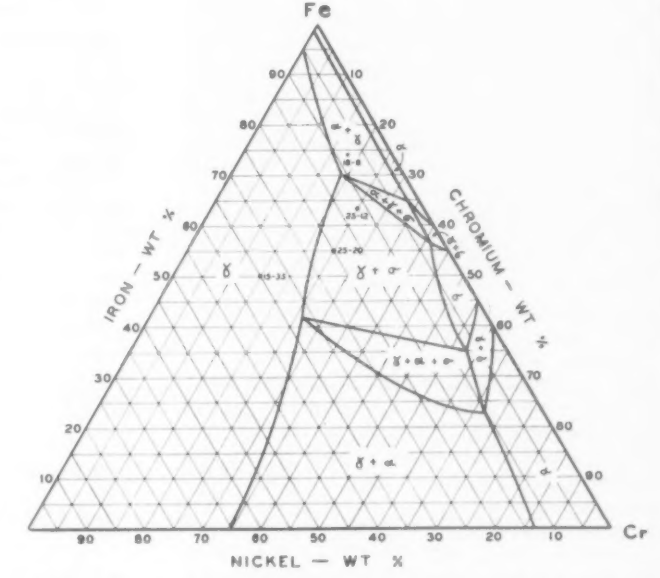


Fig. 6 Iron-chromium-nickel phase diagram at 1560° F. (850° C.) (after references 19, 44, 103, 200)

Effects of Alloying Elements

Most of the alloying elements which support formation of ferrite also considerably enhance the susceptibility of the alloy to the formation of sigma. This is particularly true with molybdenum, as was shown in great detail by Franks, Binder, and Bishop,[3] and others.[236] Similar effects are produced by silicon.[132] However, columbium, titanium, zirconium, aluminum, and others also enhance sigma formation.[56, 197]

The action of these elements is threefold. First, they lower the chromium range in which precipitation occurs. Thus, 18–8 (Cr-Ni) compositions alloyed with molybdenum or silicon are susceptible to sigma formation. Secondly, these elements considerably increase the rates of transformation—even from fully austenitic structures. Thus, 20–10 (Cr-Ni) grades containing over 3% molybdenum or silicon may exhibit some sigma even on air cooling through the temperature range in which sigma transformation occurs. Finally, the elements vary the temperature at which sigma is most stable.

In the columbium Type 347 or titanium Type 321 grades sigma precipitation is usually observed in specimens exposed for long periods (over 300 to 1000 hr.) at temperatures between 1100 and 1500° F. (595 and

815° C.).[57, 62] However, if ferrite is present, 8 hr. may be sufficient time to cause sigma formation in the columbium-bearing steel or in weld deposits, [184] Fig. 7.

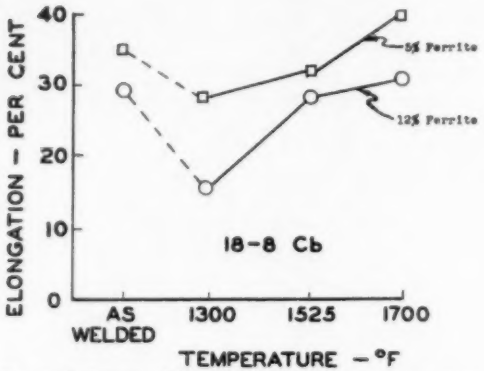


Fig. 7 Influence of heat treating temperature on room temperature ductility of Type 347 all-weld metal. Specimens were nondilution type 0.505 tensile specimens and were held for 8 hr. at heat[184]

In the titanium-bearing 18–8 (Cr-Ni) grade, raising the annealing temperature in the range of 1800 to 2300° F. (980 to 1260° C.) increases the amount of titanium carbide that is dissolved. Since this element, in its *free* state, strongly enhances sigma formation, exposing such solution heat-treated steels at temperatures at which sigma forms tends to cause the formation of greater quantities of sigma than if the titanium had been kept inactive in the form of titanium carbides. Thus, the corrosion rates of the titanium-bearing stainless steels, which have been exposed at intermediate temperatures, have been found to increase very markedly with an increase in prior-annealing temperature.[246]

In regard to the austenite formers lowering the carbon content tends to increase susceptibility to sigma formation.[41] This is due to the fact that carbon tends to tie up chromium as a carbide. Hence, roughly, for each 0.1% carbon present, the effective chromium content of the matrix will be reduced by about 1.4%. For "borderline" alloys the reduction in effective chromium content makes the difference between sigma-forming and nonsigma-forming tendencies. In addition the higher carbon content will tend to make those alloys austenitic which would normally contain some ferrite. This also inhibits sigma formation. Thus, unless long heat treatments at intermediate temperatures are employed, sigma is generally not observed in commercial alloys containing over 0.20% carbon. For example, 26–20 (Cr-Ni) heat-resistant alloys containing over 0.20% carbon required exposure of 14 days at 1600° F. (870° C.) to produce evidence of sigma precipitation.[211]

Nitrogen, on the other hand, is believed to enhance slightly the formation of the sigma phase.[5, 47] Similar results are reported for manganese [up to 2.8% Mn in 18–10–3–0.6 (Cr-Ni-Mo-Cb) alloys[78]]. Small amounts of nickel also increase the range in which sigma forms. On the other hand alloys containing over 30% nickel are not susceptible to sigma precipitation.[19]

The amount of chromium and other alloying elements present in the ferrite phase may be different from that in the austenite matrix. Thus, the chromium content of the ferrite could well be above the normal chromium content of the alloy.[12]

Sigma in Castings and Weld Deposits

Inhomogeneities in composition in castings and weld deposits are caused by coring which is due to dendritic solidification. The presence of inhomogeneities has some influence on the amount and rate of sigma formation and necessitates some differentiation among wrought alloys, castings, and weld deposits.

As 18–8 or 25–12 (Cr-Ni) castings tend to contain more ferrite than wrought steels of similar composition, cast steels can be expected to be able to form larger amounts of sigma. This is particularly true of heavy sections which, because of slow-cooling rates inside the casting, may remain sufficiently long at the elevated temperatures at which sigma may form.

Fully austenitic 25–20 castings should also be expected to be more susceptible to sigma formation than wrought grades of similar composition.

However, it is important to realize that castings are usually produced with a higher carbon content than corresponding wrought stainless grades. Since increases in the carbon content reduce susceptibility to sigma formation, the higher carbon content in cast stainless steels will reverse the effects of coring on sigma formation in partially ferritic as well as in fully austenitic compositions. Moreover, in partially ferritic compositions the higher carbon content will reduce the amount of ferrite that may form in the casting. This also decreases the susceptibility to sigma formation. On the other hand the silicon content, which is also higher in castings than in weld deposits, is likely to promote sigma formation.

In the "as-cast" state it is likely that 18–8 (Cr-Ni) castings with over 0.10% carbon and with less than 2.0% silicon will show good ductility. Similar considerations should hold true for fully austenitic 25–20 (Cr-Ni) castings containing over 0.15% carbon and less than 2.0% silicon. However, fully austenitic castings with less than 0.15% carbon, over 20% chromium, and over 2.5 or 3.0% silicon may be expected to show sigma in the as-cast state.

In the "as-welded" state sigma is rarely formed in weld deposits. The only exception may be welds with unusually high molybdenum and/or silicon content. The reason for this is that weld deposits cool quite rapidly because of the adjacent cold base metal and ordinarily have a relatively low-silicon content of about 0.5%. Thus, in the as-welded state all-weld-metal tensile specimens will generally show a ductility of over 30% elongation.

On exposure to temperatures at which sigma may form, weld deposits are more susceptible to sigma formation than wrought alloys of similar composition.[203] Ordinarily stress-relieving treatments for 6 hr. at 1000° F. (540° C.) of 18-8, 18-8-Cb, and 18-8-Ti weld deposits should not produce sigma formation.[208]

Effects of Cold Work

Prior cold work will enhance formation of sigma even more than does the presence of ferrite in alloys exposed between 1050 and 1700° F. (565 and 925° C.).[7, 33, 191] Cold work is also effective in promoting a finer distribution and a less acicular type of sigma.[34]

Rate of Sigma Formation

Normally in the Cr-Ni stainless steels the formation of the sigma phase is a fairly slow process. The rates increase progressively as the temperature is raised from 1050 to 1550° F. (565 to 845° C.), which seems to be the temperature at which a maximum rate is reached in most compositions.[12, 13, 26] This increase, for example, is true in the molybdenum-bearing 18-10 (Cr-Ni) stainless alloys.[57, 184] However, in columbium-bearing 18-10 (Cr-Ni) alloys the maximum rates seem to occur at 1300° F. (705° C.).[57, 184] The effects of temperature on the columbium- and molybdenum-bearing alloys listed in Table 5 are shown in Figs. 7 and 8, respectively.[184]

The presence of ferrite, prior cold-deformation, or favorable alloying elements may increase transformation rates still further. For example, alloys containing at least 5 to 10% of ferrite and several per cent of molybdenum or silicon may precipitate some sigma even on air cooling through the precipitation-temperature range.[12, 13, 26] Sigma particles have also been reported in castings and in weld deposits of molybdenum-[2, 20, 28] and silicon-[2, 48] bearing, chromium-nickel stainless steels.

Thus, the stainless steels with compositions susceptible to rapid sigma precipitation may have to be water quenched from temperatures above 1900 to 2000° F. (1040 to 1095° C.). The beneficial effects of quench-annealing in preventing precipitation of the brittle sigma phase was pointed out by various authors.[12, 20, 28] Characterististic results were reported by Kirkby and Morley,[12] who showed with bend specimens how sigma precipitation may lower the ductility severely, and are repeated in Table 6.

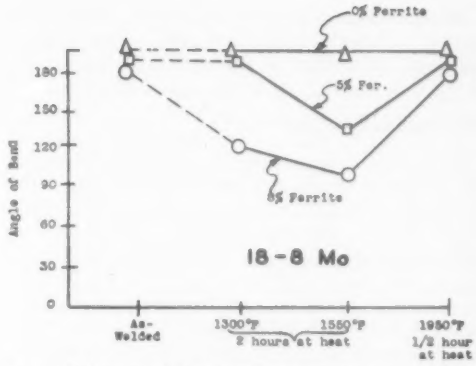


Fig. 8 Influence of heat treating temperature on room temperature ductility of Type 316 all-weld metal. Specimens were 3/16 in. square and were held for 2 hr. at 1300° F. or 1150° F. and for 1/2 hr. at 1905° F.[184]

Also, as Wylie[26] suggested, the rate of formation seems to be a function of the initial concentration of alloying elements in the ferrite. Thus, in (partially) ferritic structures exposed to temperatures above 2200 to 2300° F. (1205 to 1260° C.), the rapid diffusion rates existing at these temperatures, in addition to the solution of chromium carbides, tends to enrich the ferrite with these alloying elements. It may be expected that the more highly alloyed ferrite tends to transform to sigma more rapidly than ferrite having a low-initial concentration of alloying elements. Moreover, because some ferrite tends to transform to austenite in the intermediate temperature range, it is likely that the remaining ferrite is enriched by the ferrite-forming elements molybdenum, titanium, columbium, and chromium.[35] Such ferrite should also transform more readily into sigma.

Table 5—Anaiyses of Alloys Reported in Figs. 7 and 8[184]

Grade	*C*	*Mn*	*Si*	*S*	*P*	*Cr*	*Ni*	*Mo*	*Cb*	*N*	*Ferrite, %*
316	0.059	1.45	0.46	0.012	0.028	17.78	14.23	2.23	...	0.059	0
316	0.064	1.27	0.47	0.010	0.026	18.89	10.94	2.12	...	0.041	5
316	0.062	1.48	0.48	0.010	0.025	20.55	11.48	2.21	...	0.058	8
347	0.069	1.53	0.43	0.012	0.025	19.45	10.47	...	0.75	...	5
347	0.064	1.47	0.45	0.016	0.027	22.18	10.13	...	0.76	0.071	12

Table 6—Effects of Cooling Rate on Precipitation of Sigma[13]

Composition							Angle of bend	
C	*Si*	*Mn*	*Cr*	*Ni*	*Mo*	*Cb*	*Air cooled from 1920° F. (1050° C.)*	*Water quenched from 1920° F. (1050° C.)*
0.13	0.96	0.99	18.98	8.45	3.11	1.05	5	170
0.13	0.95	0.95	18.89	8.45	3.11	0.98	90	180

Rates of sigma formation are also increased when stresses are applied to alloys exposed to temperatures between 1050 to 1700° F. (565 to 925° C.).[9]

Dissolution of Sigma

Since sigma is much richer in chromium than austenite is, solution (or transformation) of sigma at elevated temperatures in many alloys seems to occur in a two-stage process. Since diffusion of chromium from the unstable chromium-rich sigma particles occurs at a much slower rate than that at which ferrite would form from the high-chromium area, ferrite appears as a transition phase. However, because of chromium diffusion, the ferrite is unstable and tends to transform into austenite. Thus, in an 18–8–Mo (Cr-Ni-Mo) stainless steel Dulis and Smith[237] observed that at a temperature of 2000° F. (1095° C.) ferrite occurred as an intermediate product in the process of the solution of sigma in austenite.

The temperatures at which sigma becomes unstable and tends to transform into austenite or ferrite depend upon the composition and structure of the alloy. Generally, in steels in which maximum amounts of sigma form at or below 1500° F. (815° C.), the sigma phase becomes unstable above 1700° F. (925° C.). However, some of the 18–10 (Cr-Ni) partially ferritic alloys containing several per cent of molybdenum and some columbium show sigma at temperatures as high as 1850° F. (1010° C.).

In the ordinary alloys dissolution rates do not become appreciable until temperatures above 1900 to 2000° F. (1040 to 1095° C.) are reached. Alloys containing considerable amounts of sigma may require still higher temperatures if dissolution of sigma is desired in commercially practical, short-time periods. Payson and Savage,[47] for example, stated that in high-silicon-bearing 25–20 (Cr-Ni) alloys "considerable ductility can be restored in the embrittled steels by heating at about 1900 to 1950° F. (1040 to 1065° C.) for a short time. The complete conversion of sigma to austenite may require heatings as high as 2250° F. (1230° C.)."

In low-silicon 25–20 (Cr-Ni) alloys sigma can be transformed into austenite after heating for 2 hr. at 1875° F. (1025° C.).[48] Observations by Felix and Eisermann[28] on molybdenum-bearing 20.5–11.5–4 (Cr-Ni-Mo) alloys are reported in Table 7. These results show that although annealing these highly susceptible alloys at 1920° F. (1050° C.) for 4 hr. is not sufficient to dissolve substantial quantities of sigma, at 2100° F. (1150° C.) all of the sigma has gone into solution in the oil-quenched specimen.

Identification of Sigma

In the chromium-nickel stainless steels sigma is generally identified by X-ray diffraction, magnetic, or microetching techniques.*

These studies on various alloys seem to indicate that not all sigma particles are identical. Thus, Bradley and Goldschmidt,[44] observing different X-ray patterns, suggested two modifications of sigma, one stable, and the other metastable. It was thought that the so-called stable sigma phase formed from the body-centered cubic ferrite, whereas the metastable modification was the result of transformation from the face-centered cubic austenite. Although Bradley and Goldschmidt's observations may have been correct for alloys varying considerably in chromium content, most of the more recent investigations indicate only one system of diffraction lines in the standard chromium-nickel stainless grades. The diffraction patterns appear to be the same regardless of whether the sigma formed from the austenite or ferrite. Newell[46] confirmed this stating that sigma patterns in several austenitic steels are identical with a standard pattern of fully transformed sigma in a 48% chromium-iron alloy.

Carbides precipitate in the same temperature range in which the sigma phase forms. Thus, when the sigma particles are highly dispersed and very small, it is not easy to distinguish between these two types of particles.[8]

Variations in the alloy content also seem to introduce some differences. This has been noted particularly in microscopic studies where certain etching techniques produced variations in the colors of the sigma particles in compositions of different alloys.[37] Quantitative interpretation of such observations is not possible. Time of etching is also important, since prolonged etching may cause the sigma to be dissolved out and to appear as black pits in the microstructure.[5, 7]

* A discussion of the techniques is the subject of a subsequent article.

Table 7—Notch Toughness, Brinell Hardness and Quantity of Sigma Phase in Cast Specimens of 20.5–11.5–4 (Cr-Ni-Mo) Stainless Steel After Various Heat Treatments[28]

Condition and heat treatment	*Notch toughness V.S.M. 10, mkg./cm.²*	*Brinell hardness, H 5/750/15*	*Per cent of ferrite converted to sigma**
As cast	0.7–0.8	197–207	94.5
1920° F. (1050° C.)—4 hr.—oil-quenched	3.7–4.4	184–187	Not determined
1920° F. (1050° C.)—4 hr.—air-cooled	0.8–1.1	184–193	Not determined
1920° F. (1050° C.)—4 hr.—furnace-cooled	0.3–0.4	184–200	Not determined
2100° F. (1150° C.)—4 hr.—oil-quenched	23.0–28.0	170–172	0
2100° F. (1150° C.)—4 hr.—air-cooled	18.4–19.2	160–164	15.5
2100° F. (1150° C.)—4 hr.—furnace-cooled	1.3–1.5	170–179	92.5

* Expressed as a percentage of the ferrite quantity in the specimen quenched in oil at 1150° C. No account was taken of any sigma phase that might have been produced from austenite.

Distribution of Sigma

In partially ferritic, chromium-nickel stainless steels sigma formation, in its early stages at temperatures between 1050 and 1150° F. (565 and 620° C.), occurs in the fringes of the ferrite patches. Although the initial particles may not be discernible by microscopic means, they nevertheless severely lower the bending and impact properties. Long holding periods or higher temperatures will increase the precipitated sigma particles in the ferrite patches. In fact, in a composition highly susceptible to sigma formation, all ferrite may disappear and, by two-way diffusion, may cause the formation of sigma and austenite if the alloy is held at suitably high temperatures for sufficiently long periods. Since sigma formation causes a reduction of chromium in ferrite, the relatively higher nickel content in the remaining ferrite tends to cause the transformation of some ferrite to austenite. Some of this newly formed austenite, however, may, after long exposures to temperatures of about 1400 to 1600° F. (760 to 870° C.) transform into sigma. This has been verified by experiments on a 19–9 (Cr-Ni) stainless steel containing small amounts of tungsten, molybdenum, columbium, and titanium.[239]

Although all authors agree that in partially ferritic compositions sigma formation starts in the fringes of the ferrite areas, a few also suggest that simultaneous precipitation of sigma occurs in the boundaries between austenite grains. Such an opinion was based by Riedrich[51] on the fact that the austenitic grades, which contain only a few ferrite patches, nevertheless exhibit a serious drop in bending and impact properties. It seemed unlikely to Riedrich that if sigma precipitation occurred in the ferrite alone, ductility and toughness would be lowered as severely as they were. Although the initial loss in ductility might also have been due to carbide precipitation plus sigma formation, a progressive loss would more likely be due to sigma formation. In fully austenitic steels sigma is generally found in the grain boundaries. However, when the tendency for precipitation is considerable, the phase may also appear within the grains. The particles will grow in size with time and high temperature.

Effect of Sigma on the Physical Properties

The precipitation and growth of sigma particles cause considerable changes in the physical properties of the respective alloys. Increases in hardness are accompanied by a severe decrease in ductility and toughness.[7, 12, 13] Larger particles of sigma in a segregated pattern are more effective in lowering ductility than small, finely distributed particles are.[206] Moreover, when sigma transforms from ferrite, the magnetic permeability of the alloy will be lowered.

At elevated temperatures when the sigma particles are in a very small and highly dispersed state, they are believed to be beneficial in improving the short-time tensile strength, the yield strength, and the stiffness.[136] Because of this sigma precipitation is sometimes found to be beneficial in grades employed in valves and turbine blades used at elevated temperatures.[79] As sigma precipitation considerably interferes with hot-working operations,[3] the phase should be brought into solution by suitable heat treatment prior to hot working.

In most chromium-nickel stainless steel compositions the precipitation of sigma does not become a critical factor. This depends primarily upon the particular application of the steel. However, failure to recognize or appreciate the presence of sigma in highly susceptible alloys (high in chromium and containing molybdenum, silicon, etc.) and in alloys exposed at temperatures between 1050 and 1750° F. (565 and 925° C.) may be responsible for reduced service life or poor physical properties. Also, in addition to composition, the effects of mechanical operations and heat treatments must be understood. Moreover, once sigma has formed, sufficiently high temperatures should be employed to allow the restoration of the steel to normal physical properties. This is particularly important when toughness and ductility are the major criteria.

CARBIDES

In an analysis of the effects of carbides, differentiation should be made between the corrosion- and heat-resistant grades.[208]

The Corrosion-Resistant Grades

The chromium-nickel stainless steels which are primarily used for corrosion resistance generally contain less than 0.20% carbon. Since carbon exhibits a strong affinity for chromium, it tends to precipitate as chromium carbide at temperatures between 900 and 1600° F. (490 and 870° C.). The peculiarity of this precipitation is that it preferentially occurs at the grain boundaries.[64, 91] In fact, in extreme cases when precipitation is considerable in alloys containing at least 0.15% carbon, a practically continuous network of carbides may surround each grain.[108] In addition carbides will also appear in the twin boundaries and within the grains. Such a steel, lacking substantial cohesion between grains, is rather brittle. Thus, intergranular precipitation has been believed to be responsible for reducing ductility and toughness in wrought grades, in castings, and in weld deposits.

In Fig. 9 are shown the effects of exposure of a 25–20 (Cr-Ni) steel for long periods between 1000 and 1500° F. (540 and 815° C.) on the room-temperature Charpy impact toughness.[192] The steel had the following composition:

	%
C	0.19
Si	0.44
Mn	1.47
Cr	24.24
Ni	22.02
N_2	0.063

The presence of 0.19% carbon was believed[192] to be

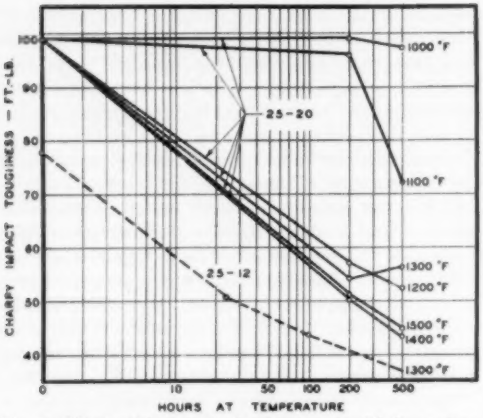


Fig. 9 Effects of long periods of exposure of fully austenitic 25–20 (Cr-Ni) steels and of a 25–12 (Cr-Ni) steel at temperatures between 1000 and 1500° F. (540 and 815° C.) upon the room temperature impact toughness[102]

responsible for sufficiently severe intergranular carbide precipitation which lowered the impact toughness from 100 ft.-lb. to about 45 to 55 ft.-lb. However, sigma precipitation may well have been the actual cause of the lowered impact toughness.

The carbide network also increases the susceptibility to stress-corrosion cracking of the intergranular type. This phenomenon has given a great deal of concern to the manufacturers of aircraft-engine manifolds. Corrosion rates are also increased severely by the intergranular precipitation of carbides.

Precipitation of carbides between 900 and 1600° F. (490 and 870° C.) is generally called sensitization. The temperature range in which this precipitation occurs is known as sensitization range.

The effects of time and temperature on sensitization are evident from Fig. 10.[51]

The carbide network is most detrimental when it is formed at the lower end of the sensitization range. Higher temperatures and longer holding periods cause agglomeration of the carbides which improves cohesion and resistance to intergranular corrosion. Nevertheless, short periods at the higher temperature may not be sufficient to allow agglomeration.

Similar considerations hold true in weld deposits where a lower than normal ductility corresponds to a relatively continuous carbide network and higher ductility with agglomerated carbides in the dendritic structure.[306]

The formation of chromium carbides in the grain boundaries reduces the free-chromium content until it has been replenished by diffusion from the interior of the grains. However, if sufficient diffusion has not taken place, the lower chromium content in the grain boundaries may, at room temperature, cause transformation of the grain boundary area into ferrite.[119] This was indicated by Winterton[119] who found that 12–8–2.5 (Cr-Ni-Mo) weld deposits exhibited ferrite in the grain boundaries when the alloy was heated for 10 min. at 1560° F. (850° C.). This formation of ferrite considerably reduced ductility. Similarly, ferrite was believed to appear in the grain boundaries of 25–20 (Cr-Ni) weld deposits heated for 10 min. between 1605 and 2010° F. (875 and 1100° C.). This "ferrite" formation appeared most pronounced at 1605° F. (875° C.).[134] It might be possible, however, that sigma was formed instead of ferrite, even though the temperatures seem somewhat high for sigma formation.

Carbides, in addition to their effects on intergranular corrosion, should also be recognized for their ability to increase tensile strength and reduce elongation. Thus, in severe cases of carbide embrittlement ductility may be lowered as severely as if sigma particles had been formed.

The Heat-Resistant Grades

Most of the conventional heat-resistant grades contain over 0.20% carbon. In these grades carbides tend to precipitate between 1200 and 2000° F. (650 and 1095° C.). In the upper part of this range agglomeration of carbides may take place after precipitation;

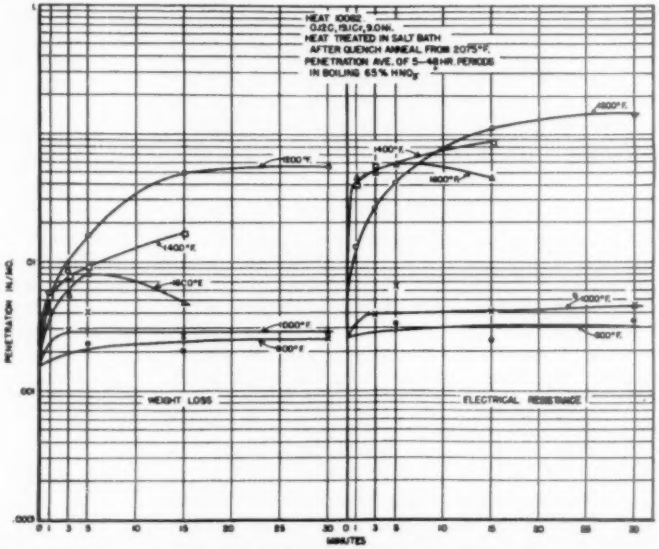


Fig. 10 Corrosion rates of a 0.12% C, 19.1% Cr and 9.0% stainless casting in nitric acid after sensitization at 800 to 1600° F. (425 to 870° C.) for 1 to 3 min.[51]

however, up to 1800° F. (980° C.), or slightly higher, the precipitated carbides in creep-test specimens show practically no noticeable agglomeration.[208]

Stability of the chromium carbides also increases considerably with increases in the carbon content. Typical data for 15–35 (Cr-Ni) stainless steels are shown in Fig. 11.

In the heat-resisting alloys most of the fine-carbide precipitation occurs within the grains rather than at the grain boundaries, where it occurs in the low-carbon, corrosion-resisting grades. This difference in carbide precipitation may account for the improved hot ductility that follows an increase in carbon content.[208] Data illustrating the effects of carbon content on the not ductility of 15–35 (Cr-Ni) stainless castings are shown in Fig. 12. These results may also help to explain why an increase in carbon content, which contributes to improved creep strength and hot ductility, reduces the tendency of 15–35 (Cr-Ni) weld metal to crack.

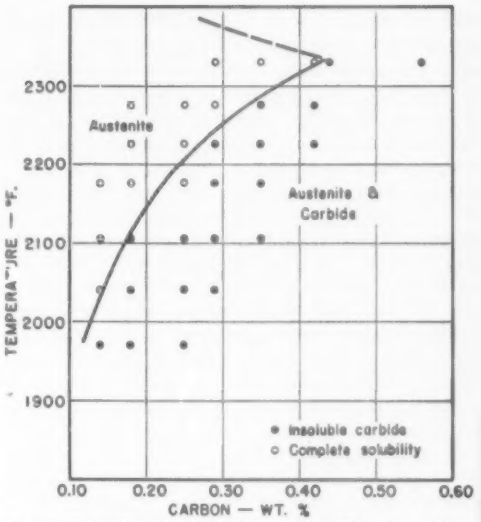


Fig. 11 Solubility of carbide in 15–35 (Cr-Ni) heat resistant castings[205]

Structure of Carbides

Recent electron microscopic studies by Mahla and Nielsen[71, 175, 221] on the structure of carbide particles begin to explain their versatile characteristics and effects. Thus, on sensitization at 1250° F. (675° C.) the carbide particles tend to precipitate in a thin dendritic, nearly two-dimensional form which is typical of a high rate of diffusion-controlled particle growth.[221] In this dendritic form the particles are believed to account readily for the observed rapid sensitization and recovery on very short-time, heat-treating cycles. However, prolonged heating periods and/or higher temperatures tend to change the unstable dendritic carbide to a carbide of geometrical habit determined by the metal lattice planes on which it is growing.[221]

The distribution and form of the carbide particles are likely to have an important influence on the susceptibility of the stainless alloy to intergranular corrosion. However, no definite correlation of carbide form with standard corrosion tests has as yet been undertaken.

CORROSION RESISTANCE

In stainless steels corrosion resistance is generally associated* with the formation of a thin chromium oxide

* Three other theories proposed to explain the corrosion resistance of stainless steels are (1) the Electron Configuration theory of Uhlig,[198] (2) the physically adsorbed-gas theory of Fontana and Beck, and (3) the unified-mechanism theory suggested by Mears and Brown.

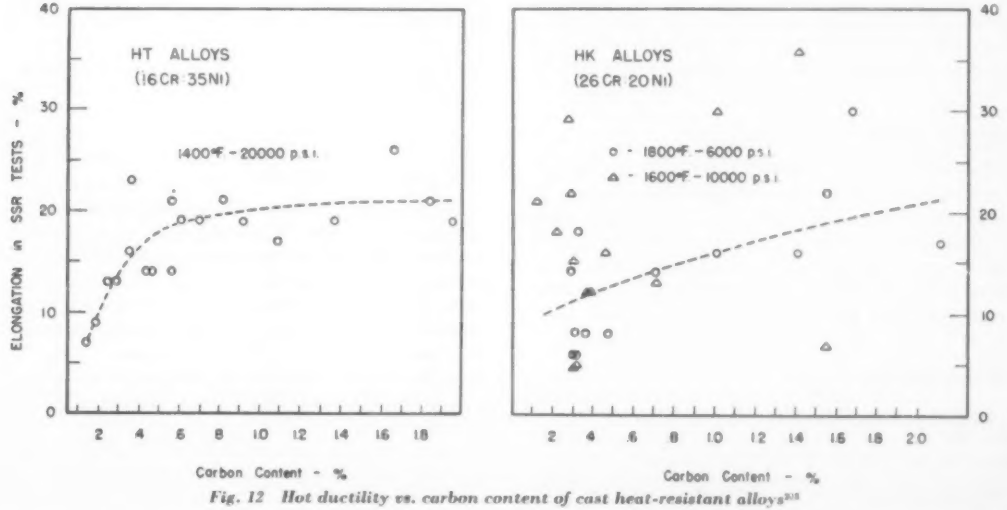

HT ALLOYS
(16 CR-35 NI)
1400°F - 20000 p.s.i.
ELONGATION in SSR TESTS - %
Carbon Content - %
HK ALLOYS
(26 CR-20 NI)
○ - 1800°F - 6000 p.s.i.
△ - 1600°F - 10000 p.s.i.
Carbon Content - %

Fig. 12 Hot ductility vs. carbon content of cast heat-resistant alloys[205]

film† on the surface of the steel.[82, 87, 120] Moreover, environments which are oxidizing in nature tend to repair any breaks in the film which may occur in service by promoting the formation or replenishment of the protective oxide film. On the other hand reducing conditions cannot maintain the film in good repair and thus, if breaks are present in the protective film, corrosion may occur.[82, 87] Thus, as the austenitic stainless steels are mainly used in service operations exposed to corrosive environments, it is important that fabricating procedures do not introduce changes which reduce the resistance of the material to corrosive attack. Moreover, if unfavorable conditions have been set up, it may become necessary to use appropriate heat treatments to bring the stainless steel into a state which exhibits satisfactory corrosion resistance.

Distinction should be made between the three major types of corrosion. These are (1) general corrosion, (2) intergranular corrosion, and (3) pit corrosion. *General corrosion* represents a relatively uniform attack upon the matrix constituents, that is, the austenite and ferrite phases. *Intergranular corrosion* indicates preferential attack along the grain boundaries. It is generally associated with severe intergranular precipitation of carbides. *Pit corrosion* occurs in some generally weak chemical solutions which usually contain chlorides. It is caused by a local break in the protective chromium oxide film.[82]

Effects of Carbides

From Bain, Aborn, and Rutherford's classical studies[50] the mechanism of intergranular corrosion in stainless steels is generally believed to consist of chromium impoverishment at the grain boundaries which results from the precipitation of chromium-rich carbides. These chromium carbides are thought by most authors to lower the chromium content which is in solid solution near the grain boundaries and, thus, to reduce the corrosion resistance in these areas. In addition these particles may well set up local internal stresses and cause the formation of local electrolytic cells.

Effects of Ferrite

The presence of ferrite seems to be a minor factor. Only in severely corrosive environments may ferrite increase the general corrosion rates by causing local electrolytic-cell action. In fact in alloys susceptible to carbide precipitation, the presence of ferrite seems beneficial because carbides tend to precipitate preferentially in the ferrite patches.

Effects of Sigma

Although the possibility of chromium depletion through the precipitation of chromium carbides is generally mentioned by most investigators, the fact that sigma formation also decreases the chromium content of the matrix is usually overlooked. Thus, the greater the amount of sigma precipitation the greater is the chromium depletion of the matrix.[225] In certain highly corrosive solutions the lower chromium content of the matrix as well as possible local electrolytic-cell action may considerably increase corrosion rates.

However, in most commercial solutions in which the stainless steels are ordinarily used, the effects of the sigma phase seem negligible.[13] These considerations are also true for many of the standard test solutions containing reducing acids. Thus sigma formation in stainless steels does not noticeably increase the rates of attack by boiling acidified copper sulphate, *air-free* sulphuric acid, and nitric-hydrofluoric acids.[196] Sigma only reduces the corrosion resistance of the stainless steel in strong, particularly oxidizing liquors. This is true for most of the testing solutions which, because of the need to establish short testing periods, are highly corrosive. It is very important to realize that, particularly in these alloys in which sigma is present, corrosive behavior established by testing liquors may not at all correspond with behavior in similar, but considerably weaker corrosive applications.

In 25% sulphuric acid (aerated) the corrosion rates are increased by as much as five to twenty times by the presence of sigma. In boiling 65% nitric acid solutions the differences are a great deal more severe and may amount to as much as several hundred times.[245] Moreover, a fine intergranular precipitate of sigma reduces corrosion resistance more effectively than large coalesced particles.[196] Thus, in wrought or welded compositions, in which sigma is present, a heat treatment between 1400 and 1600° F. (760 and 870° C.), which causes coagulation of the sigma particles, is believed to improve corrosion resistance.[196, 243]

Sigma distribution also seems of major importance. This was discussed previously in considerable detail[2] for molybdenum-bearing alloys. Additional variables are introduced by alloy depletion on initial sigma formation which, on prolonged heating, is reduced because of homogenization. This, in turn, will to some degree increase corrosion resistance.[12]

Intergranular Corrosion

Intergranular corrosion is the result of two factors acting in sequence. First, exposure to undesirable temperatures induces sensitization, that is, intergranular precipitation of carbides. Secondly, there must be a sufficiently strong corrosive medium to attack the sensitized areas. In extreme cases significant attack has been produced by ordinary tap water.

In most cases the causes of intergranular corrosion can be related conclusively to the intergranular precipitation of carbides. Closely connected with this is the so-called "chromium depletion" theory which explains that the formation of chromium carbides depletes the grain boundaries of chromium and, thus, renders them

† Actually a small amount of iron oxide (Fe_2O_3) and nickel oxide (NiO) may also be in the surface film.[94, 175, 181]

more susceptible to corrosion.[50, 64, 78, 91, 108, 139, 168, 177] Prolonged heating near 1500° F. (815° C.) allows replenishment of "free" chromium by diffusion toward the grain boundaries and is credited with eliminating somewhat the degree of intergranular corrosion.

A few cases of intergranular corrosion cannot be explained satisfactorily by the precipitation of a carbide network alone. Thus, Uhlig[68] observed intergranular corrosion in a vacuum-melted stainless steel specimen containing 17.6% Cr, 24.0% Ni, 0.003% C, and 0.006% N, after heating 169 hr. at 930° F. (500° C.). No intergranular attack was observed in the same alloy when it was quenched from 2010° F. (1100° C.). Uhlig believed that the attack at the grain boundaries was caused by a transformed alloy phase which was not determined.

These and other observations[174] suggest that intergranular corrosion is initiated by the so-called pit nuclei. These consist of those small particles which lie near the surface of the metal. As such they will weaken the protective chromium oxide surface film on the stainless steel. Once this film has been pierced, corrosive attack may progress along the grain boundaries which, because of internal lattice strains, are attacked more readily than the grains themselves.

Intergranular carbides, as such, might well act as pit nuclei which, when present even in small quantities, might suffice to weaken the protective chromium oxide film at the grain boundaries. Thus, a relatively few precipitated carbides and nitrides could be responsible for the intergranular attack observed by Uhlig.

As the carbon content is increased, more carbides can form which in turn increases the number of pit nuclei. The fact that increasing the carbon content increases intercrystalline corrodibility and reduces resistance to local corrosion has been pointed out by various authors.[72] Alloys in which the carbon is brought into solution by quenching from high temperatures do not exhibit significant difference in the corrosion rates for carbon-content variations between 0.05 to 0.25%.[72, 77]

Passivation[142] in oxidizing solutions is beneficial in that such treatments tend to increase the thickness of the chromium oxide surface film. However, unless careful control is employed, the passivating solution may also break through the film at the pit nuclei. This is often evidenced by severe pits in passivated stainless steels.*

In the stabilized grades the columbium or titanium carbides do not deplete the chromium in solid solution which is available in their immediate vicinity. Thus, they may be covered by a sufficiently thick chromium oxide film which gives these alloys protection against the action of most of the corrosive and etching solutions. However, strong solutions may cause pitting which, because of the uniform distribution of the stabilized carbides, has a transgranular appearance.[174]

Effects of Deformation

Cold work and straining increase the rate of carbide precipitation in alloys exposed in the sensitizing temperature range. However, because precipitation in cold-worked stainless steels also occurs in slip planes, the degree of intergranular precipitation is not as severe as in annealed grades. Consequently, cold work is somewhat beneficial as it reduces the susceptibility of an austenitic stainless steel to intergranular corrosion.[28,91,151] These results may well be related to Mahla and Nielsen's[231] observation that cold deformation before sensitization prevents the formation of the relatively large dendritic carbide particles. On the other hand, cold deformation after sensitization tends to break up the initial dendritic carbide particles and as such is also beneficial. The effects of sensitization and of prior or postcold deformation on corrosion rates in the standard boiling nitric acid test[232] of an 18–8 (Cr-Ni) stainless steel (Type 304) are illustrated in Fig. 13, curves *A* to *D*. Curve *E* represents the steel in the "quench-annealed" state [water quenched from about 1950° F. (1065° C.)].

The general corrosion rates are also slightly increased by deformation. For the 18–8 (Cr-Ni) steel shown in Fig. 13 this is illustrated by Curve *F* which represents the quench-annealed steel (in Curve *E*) after a cold reduction of 80%. In practice strains caused by threading or by punching out holes have been found to be responsible for accelerated corrosion rates in the strained areas.[116] Normal corrosion resistance may be restored by annealing at temperatures high enough to remove the effects of straining.[125]

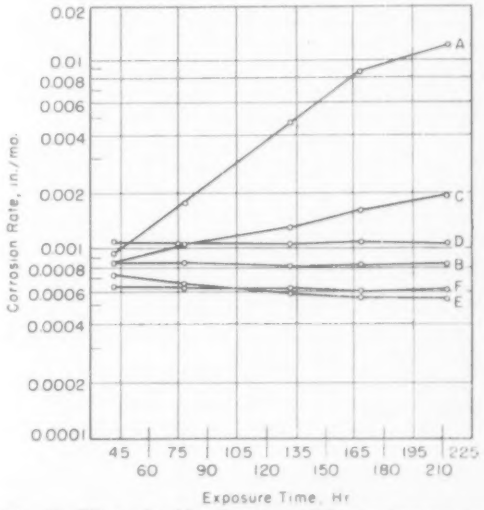


Fig. 13 Effect of cold reduction and heat treatment on corrosion rates in nitric acid of 0.07% C, 18.65% Cr and 8.92% Ni stainless steel

A—Sensitized 1 hr. at 1250° F., W. Q. B—80% cold-reduced, sensitized. C—Sensitized, 80% cold-reduced. D—Sensitized, 80% cold-reduced, sensitized. E—Annealed. F—As cold-reduced 80%.[231]

* The primary purpose of the commercial passivation treatment is the cleaning and pickling action in which the removal of surface contaminants is far more important than the promotion of the natural film-forming property of the steel.[56]

The increase in the general corrosion rates of the quench-annealed and cold-deformed specimens, which are not likely to contain carbides, is probably of an electrochemical nature. Nevertheless, Rohn[147] tied the decrease in corrosion resistance of cold-deformed grades to carbon content. Thus, he found that austenitic and austenitic-ferritic stainless steels containing over 12% chromium and up to 20% nickel are corrosion resistant after deformation, that is, their corrosion properties are not affected by cold deformation, if the carbon content is kept below 0.02 to 0.04%.

Stresses, though to a lesser degree than actual deformation, also increase general corrosion rates.[137]

Other Effects

The degree of intergranular corrosion is also affected by other variables such as grain size, to be discussed later on, and the previous heat treatments to which the steel has been subjected. Preferential precipitation on existing carbide particles can also occur if, during previous annealing, all the carbides in the steel have not been dissolved. The carbides which remain undissolved reduce the amount of carbon available for intergranular precipitation. Thus, on subsequent reheating in the sensitizing range, the results of intergranular corrosion may be less severe, i.e., the steel behaves in a manner which is similar to alloys of lower carbon content.[80]

Prevention of Intergranular Corrosion

Intergranular corrosion may be prevented or minimized by several methods. They are associated with (1) a full anneal followed by rapid cooling, (2) an immunizing heat treatment, (3) the presence of ferrite, (4) the use of extra-low carbon grades, and (5) the use of stabilizing elements. Each will in some way affect the formation or distribution of the carbides.

The choice of these methods primarily depends upon the corrosive requirements and the ability to utilize certain final heat treatments on the finished structures

Moreover, distinction should be made between heat treatments that prevent intergranular precipitation at any temperature and those that prevent intergranular precipitation as long as temperatures above 600° F. (315° C.) are not reached. [Of course, ordinarily, carbide precipitation does not become appreciable until about 900° F. (490° C.).]

Annealing the chromium-nickel stainless steels between 1850 and 2050° F. (1010 and 1120° C.) for about 1/2 to 1 hr. per in. of thickness will bring most of the chromium carbides into solution. Temperatures in the upper part of the range should be used for the stainless steels with a higher carbon (above 0.10%) content and/or chromium-nickel content. Following quenching at sufficiently rapid rates, an austenite will be retained which is supersaturated with carbon.

The effects of annealing treatments on a 19–9 (Cr-Ni) alloy containing 0.12% carbon are shown in Fig. 14.[81] The data were obtained on 1/8 in. thick strips which allowed rapid heating rates.

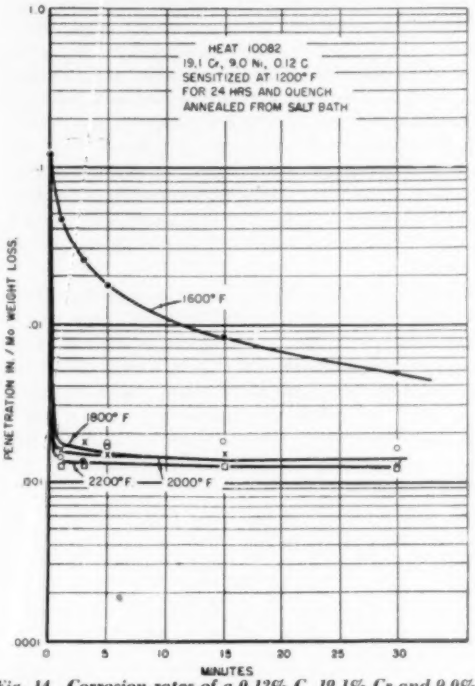


Fig. 14 Corrosion rates of a 0.12% C, 19.1% Cr and 9.0% Ni stainless casting in nitric acid after heat treatments at 1600 to 2200° F. (870 to 1205° C.) for 1 to 30 min.[81]

Quench-annealing is the most efficient heat treatment which prevents intergranular corrosion in the chromium-nickel grades. However, if subsequent processing of these steels causes their heating into, or passing (slowly) through, the temperature range between 800 and 1600° F. (430 and 870° C.), the sensitizing range, chromium carbides are again precipitated in the grain boundaries. The effect of cooling rates and of welding on carbide formation were discussed in a previous paper.[2]

The temperatures required to cause carbide solution by annealing may be too high for many fabricated structures. Thus, quenching from temperatures above 1850° F. (1010° C.) may be responsible for serious distortion.

The *immunization heat treatment* [76, 80, 91, 117, 137, 151] consists of heating the alloy in the upper temperature range in which the chromium carbides form, that is, between 1350 and 1550° F. (730 and 845° C.). Generally, temperatures between 1500 and 1550° F. (815 and 845° C.) are preferred. The principal beneficial effect of this treatment is believed to be the diffusion of chromium into the chromium-depleted areas adjacent to the precipitated carbides.

In wrought 18–8 (Cr-Ni) stainless steels[213] immunization can be accomplished in a few hours at 1650° F. (900° C.). This also seems to hold true when the carbon content is somewhat above normal. If the final rolling temperature of 18–8 (Cr-Ni) grades can be controlled between 1400 and 1600° F. (760 and 870° C.), immunization can be accomplished in as little as 1 hr. at 1400° F. (760° C.).[203]

In cast stainless steels considerably longer periods seem to be required to accomplish immunization. In these grades about 24 hr. or more may be required at immunization temperatures. In fact in the more sluggish, highly alloyed, stainless steels as much as 48 to 96 hr. may be necessary. As a commercial treatment this may be highly impracticable.

The effects of time and temperature on immunization are evident from Fig. 15.[81, 172] At 1400 and 1600° F. (760 and 870° C.) immunization is explained by carbide agglomeration and chromium diffusion. At 1800° F. (980° C.) carbide solution is the principal factor.

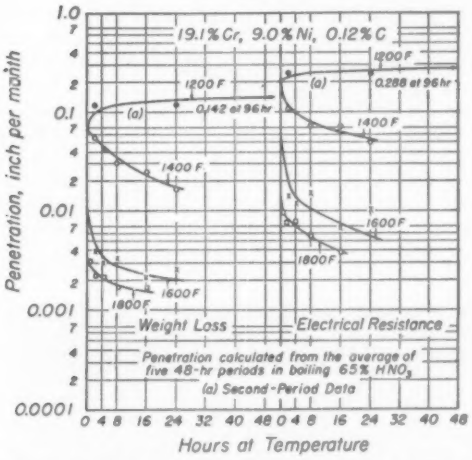


Fig. 15 Effect of holding temperatures of 1200 to 1800° F. (650 to 980° C.) for 2 to 96 hr. on corrosion rates in nitric acid of a 0.12% C, 19.1% Cr and 9.0% Ni stainless casting[81, 172]

When cold work has been introduced in the steel, the time for chromium diffusion can be reduced considerably.[80] Moreover, the precipitation of carbides in slip planes, which occurs because of cold work, is beneficial because it reduces the amount of precipitation in the grain boundaries.

Coagulation of the intergranular carbides occurs at the same time as chromium diffusion. Thus, the initial, relatively continuous, carbide films are broken up. This improves resistance to intergranular corrosion.[100, 108]

As this treatment tends to cause precipitation of a maximum amount of carbon, it consequently ties up an appreciable quantity of chromium and lowers the general corrosion resistance somewhat. Thus, with a carbon content of 0.15%, the effective chromium content is lowered by about 1.5 to 2%.[80] However, since the depletion of chromium is uniform and not intergranular, the reduction in corrosion resistance is overall Thus, if the chromium content is high enough (above about 15% chromium), the amount that has combined with carbon may not lower corrosion resistance noticeably.[213] In the commercial 18–8 (Cr-Ni) stainless steels which generally contain 0.06 to 0.08% carbon, the effective chromium content would be in the range from 17 to 18%, which is not low enough to produce a noticeable loss of corrosion resistance.*

Immunization is advisable only whenever structural design or the lack of suitable equipment does not allow a full-annealing treatment. Thus, welded assemblies in which carbide precipitation occurred in the heat-affected zone may require this heat treatment. Otherwise, the heat-affected zone will be susceptible to intergranular corrosion.[76]

Immunization also may be necessary in equipment frequently heated in the sensitizing range. Monypenny[80] cited as example a tubular heat exchanger made of an 18–8 (Cr-Ni) steel containing about 0.08% carbon. The exchanger was used at 930 to 1110° F. (500 to 600° C.) in contact with corrosive gases. Thorough immunization at 1560° F. (850° C.) caused the equipment to give satisfactory service.

The important point to remember is that the immunizing heat treatment is not as efficient in reducing intergranular corrosion as are quench-annealing or the use of the extra-low carbon or stabilized stainless grades. However, in certain applications this method may be the most economical one which still produces steel giving satisfactory service.

Although the immunization heat treatment of a welded section may provide satisfactory resistance to intergranular corrosion, welding of immunized structures is undesirable. Welding causes the carbides in the heat-affected zone to redissolve and reprecipitate in the grain boundaries when a second bead is deposited.[91]

The *presence of ferrite* considera'bly reduces the susceptibility to intergranular corrosion in sensitized grades exposed to strong solutions. In stainless steels exhibiting such duplex structures, carbides tend to precipitate in the ferrite boundaries and not in the boundaries between two austenite grains.[25, 91, 101, 133, 139, 142, 151, 161, 177] Moreover, as ferrite tends to contain more chromium than the austenite, chromium depletion is not as severe.[25, 101, 177] Thus Scherer, Riedrich, and Hoch[25] suggested the commerical use of stainless steels containing between 10 and 20% ferrite. Such alloys should be annealed between 1400 and 1650° F. (760 and 900° C.) to gain full resistance to intergranular corrosion.

The *use of extra-low carbon grades* was discussed in a previous review.[2] Additional information on the cor-

* In the few cases[240] in which chromium depletion resulting from precipitation of chromium carbides has been believed responsible for "excessive" general corrosion rates, other factors may also have been responsible.

rosion resistance of wrought[241] and welded[196, 242, 244] compositions can be found in various recent articles.

In most welding operations satisfactory results are obtained with the Type 304 stainless grade containing a maximum of 0.08% carbon. Postannealing after welding is generally not necessary and there are numerous examples of the successful use of welded structures and vessels in the as-welded condition. However, in cases of exposure to severely corrosive environments and/or in the sensitizing range, the use of the new extra-low carbon grades, which contain up to 0.03% carbon, may be necessary. Such alloys are now produced commercially.

The use of carbide-stabilizing elements represents one of the most important methods used to prevent intergranular corrosion. Small additions are made of certain elements which exhibit a strong affinity for carbon. These elements form their own carbides and, when present in sufficient quantities, prevent the precipitation of chromium carbides. Most commonly used as stabilizers are columbium, titanium, and tantalum. Their action has been discussed in detail in a previous review.[2]

Effects of Welding Processes

Welding processes may also introduce variables which affect corrosion resistance. Already mentioned[2] were the important effects of cooling rates, particularly in their influence on the heat-affected zone. Care also has to be taken to insure that as little carbon as possible is introduced during welding.

Thus, the electric-arc, electric-resistance, submerged-melt, and inert-gas welding processes are generally considered to introduce none or negligible amounts of carbon.[2] On the other hand oxyacetylene welding may, unless the flame has been properly adjusted, cause a significant increase in the carbon content.

Considerations such as these will determine whether the weld offers corrosion resistance comparable to the parent metal or exhibits either inferior or even superior corrosion resistance.[109, 110]

Preheating even below the sensitizing range is not recommended. Austenitic stainless steels are not air-hardening; moreover, preheat treatments would, upon welding, reduce the rate of cooling through the sensitizing temperature range.[137] The only major exception are the columbium-bearing stainless steels (such as Type 347) in which preheat treatments are necessary for the elimination of cracking during the welding of heavy sections.

As stainless steels are mostly used over a wide variety of corrosive conditions, particular care has to be taken to select the stainless grade most suitable for the particular conditions present in each application. Economical considerations have to be balanced by the desirability for better service given by the more expensive, more highly alloyed grades. These factors make a careful analysis of the various characteristics associated with the properties, fabricating processes, and economics of stainless steels very important.

There should be no need to use a highly alloyed grade in applications in which an ordinary 18-8 alloy would give satisfactory service. This is particularly true in corrosive applications where the fabricating processes employed do not introduce detrimental, intergranular carbide precipitation or where, if such a network has formed, subsequent heat treatments may restore satisfactory service properties.

CRACK SENSITIVITY

Various factors may cause cracking in stainless weld deposits. This is particularly true in cases where residual or induced stresses in the weld are of serious magnitude. This may occur when welding restrained or grooved sections in which shrinkage, notches, or restraint may induce cracks and is of particular importance when stainless steel electrodes are used to weld materials having compositions different from those of the electrodes. In these cases serious residual stresses are caused by the different coefficients of expansion. Welding of stainless clad steels and armor plates are only two examples in which such problems are encountered.

As Thomas[4] pointed out, distinction may be drawn between two types of cracks.

The first and more common type are longitudinal- or centerline-bead cracks, extending generally from crater cracks, root notches, or entrapped slag. Because these cracks usually reach the surface, they may be easily de-

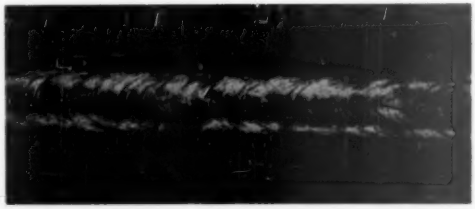


Fig. 16 Longitudinal or centerline crack in a 25-20 (Cr-Ni) weld deposit[4]

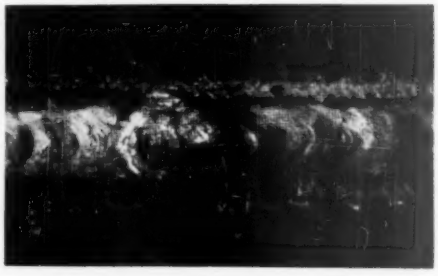


Fig. 17 Typical crater crack in 25-20 (Cr-Ni) weld deposit[4]

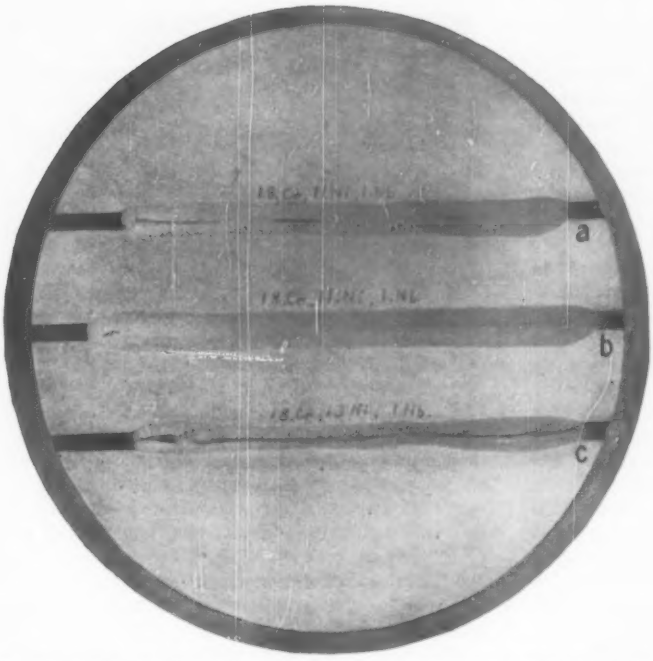


Fig. 18 Longitudinal cracks in single bead type 18–8 Cb (18–8 Cb) submerged-melt welds, 4/10 actual size[225]

Weld metal: (a) and (b) 18% Cr, 11% Ni, 1% Cb; (c) 18% Cr, 13% Ni, 1% Cb

tected by visual or macroscopic inspection. A typical longitudinal- or centerline-bead crack in a 25–20 (Cr-Ni) weld deposit from titania-coated, arc-welding electrodes is shown in Fig. 16. A crater crack in a 25–20 (Cr-Ni) weld deposit, which differs from the longitudinal-bead crack only in size, is shown in Fig. 17. Longitudinal cracks in single-bead, submerged-melt welds deposited on a columbium-bearing 18–13–1 (Cr-Ni-Cb) base composition are shown in Fig. 18. These cracks are usually filled with slag as they are open up to the top surface of the weld bead at a high temperature.

A longitudinal-bead or crater crack in an 18–8 (Cr-Ni) submerged-melt, single-bead weld on a carbon steel which did not reach the surface is shown in Fig. 19. The fine columnar dendritic growth on the top surface of the weld suggests that the surface solidified before the bulk of the weld metal did. Cracking in the relatively weak columnar structure might well have occurred on cooling between 1600 and 1400° F. (870 and 760° C.) at which temperatures the 18–8 (Cr-Ni) steels possess low ductility and tensile strength.[226, *]

The second type of crack is the so-called "check" crack. They are generally very fine and may extend in any direction. These check cracks are generally examined by means of radiographic or gamma-ray testing techniques. Figure 20 shows an example of the severe cracking which may be encountered in certain fully austenitic, multibead arc welds. These cracks are generally believed to occur during the initial solidification and also as a result of the reheating caused by each subsequent welding bead.[228] This latter type of cracking is also illustrated in Fig. 21. It is an example of the kind of crack which occurs solely as the result of

* Detailed information on the mechanical properties of various steels at elevated temperatures has recently been reported by Miller and Heger.[227]

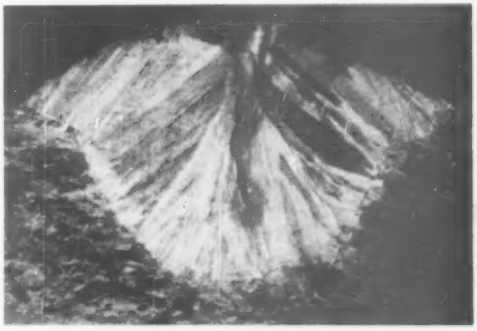


Fig. 19 Crack in single bead 18–8 (Cr-Ni) submerged-melt welds that did not reach the surface. Magnification 6 ×[228]

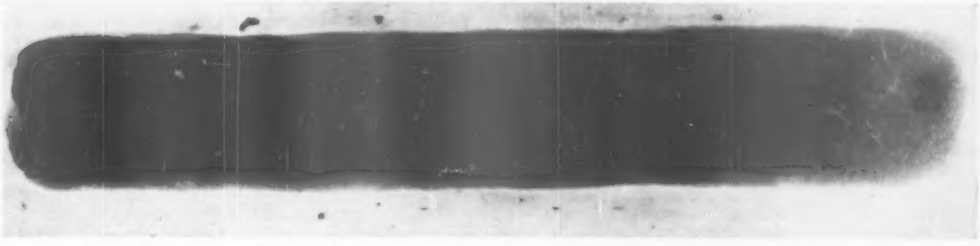


Fig. 20 Radiograph illustrating check cracks of 18–8 Cb (Cr-Ni-Cb) deposit made by electric arc welding[225]

reheating sound weld metal and of depositing additional weld metal on it. In the case shown in Fig. 21 the "buttered" layer was stress annealed and its soundness confirmed prior to further welding. Fully austenitic deposits and some which retain less than about 5% of (delta) ferrite are liable to give trouble in this way. More than 5% of ferrite will prevent cracking. In the case of certain slightly duplex welds secondary (check) cracking occurs only if the initial deposit is stress annealed prior to further welding.[223]

Sometimes the check cracks in the surface may be so fine that they may even defy radiographic examination. In these cases fluorescent penetrant inspection procedures are most suitable for the determination of these very fine cracks.

Weld-metal cracking generally can be traced to the action of six major factors: (1) microstructure, (2) composition of electrode and of the parent metal of the steel, (3) welding technique, (4) electrode coating, (5) geometry of weld, and (6) degree of restraint.

Both the obvious bead cracks and the concealed check cracks may occur at elevated temperatures. Such hot cracking is resisted by hot strength and minimized by hot ductility. These depend on microstructure and composition. Where enough data are available, it is usually possible to trace this relationship.[208]

Effects of Microstructure

In weld deposits the crack sensitivity of fully austenitic welds containing about 18% chromium and 8 to 12% nickel may be considerably reduced by the introduction of ferrite in the microstructure. Scherer, Riedrich, and Hougardy[22, 170] and Thomas[229] were among the first to suggest that the composition of the electrode be adjusted to obtain 5 to 35% ferrite in the otherwise austenitic weld deposit. Subsequent studies by Feild, Bloom, and Linnert[157–180] and Thomas[4] also showed that at least 5% ferrite should be formed in the microstructure to avoid welds susceptible to microfissuring.

The presence of ferrite seems important primarily in the 18–8 (Cr-Ni) type grades.* The more highly alloyed 25–20 (Cr-Ni) grades generally are more sensitive to cracking than the partially ferritic 18–8 (Cr-Ni) grades and less sensitive than the fully austenitic 18–8 (Cr-Ni) grades are.[207] To a considerable extent this may be due to the fact that the 25–20 (Cr-Ni) grades may contain a higher carbon content (up to 0.20% carbon) than the 18–8 (Cr-Ni) type electrodes, and, therefore, have higher hot strength. Another important factor

* 18–20% Cr, 8–12% Ni.

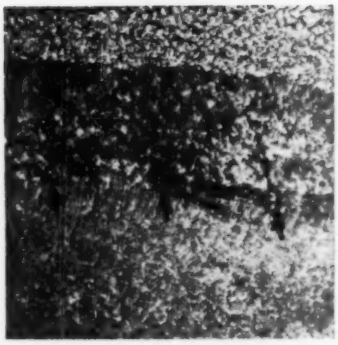


Fig. 21 Check cracks in 18% Cr, 9% Ni, 2.5% Cu and 1% Cb weld metal caused by further welding over a stress annealed deposit. Parent metal 18% Cr, 13% Ni and 1% Cb. Magnification 4 ×[223]

is that the 25–20 stainless steel has a much lower coefficient of expansion than the 18–8 (Cr-Ni) grade.

Thus, it seems that at the present state of knowledge it is not possible to produce a totally austenitic 18–8 (Cr-Ni) type weld deposit, with or without columbium, which will be free from microfissures with the carbon limitations imposed on the alloy for corrosion resistance.[190]

The effects of microstructure on the tensile properties of several austenitic and partially ferritic weld deposits are given in Table 8. The loss of ductility and strength in the fully austenitic weld deposits was caused by microfissures in the weld metal.[190]

These results seem to be in contradiction to experiences on wrought (homogenized) grades which are most ductile when fully austenitic. Of course, sound, fully austenitic weld metal would also be most ductile. It is possible that these differences may be explained by the distribution of carbon and/or other minor residual or alloying elements, nonmetallic inclusions, and grain-boundary films. Thus, Norén and Hellerström[204] believed that compositions which form a small amount of (delta) ferrite give a smaller solidification range than fully austenitic compositions. This smaller solidification range results in a reduced segregation of oxygen and other elements. These factors seem to be the primary cause of the formation of hot cracks. A fully austenitic composition will result in slower solidification which results in a more severe formation of microsegregations and hot cracks.

Earlier the advantageous role of ferrite in weld deposits was explained by Thomas[4] who believed that "the ferrite constituent is harder and stronger than

Table 8—Effects of Microstructure on the Tensile Properties of 19-9 (Cr-Ni) Stainless Weld Metal[190]

Alloy	*Structure*	*Ultimate strength, psi.*	*Yield point, psi.*	*Elongation, %*	*R.A., %*
19–9	Austenitic	70,750	54,000	13.0	27.8
19–9	Austenite + 10% ferrite	92,250	63,500	33.0	32.9
19–9 Cb	Austenitic	48,500	...	7.0	8.9
19–9 Cb	Austenite + 10% ferrite	92,750	62,000	40.0	50.0

the austenite matrix, and its presence in a finely dispersed dendritic pattern is a deterrent either to the formation of cracks or to the growth of the cracks once formed." However, all of the recent studies indicate that microsegregations represent the most important factor.

On the other hand it should also be remembered that ferrite may cause detrimental effects. Thus, in corrosive applications the presence of ferrite usually increases the general corrosion rates. In highly corrosive environments fully austenitic structures may often be necessary. Fortunately, in many types of chemical equipment crack sensitivity and good ductility are not of primary importance.

Ferrite may also be undesirable because of its effects in enhancing sigma formation. This is particularly true in alloys in which molybdenum, silicon, or columbium are present in excess of the usual residual amounts. The quantities of ferrite that may or may not be desirable primarily depend upon the application in which the welded section is used. As such in service at elevated temperatures ferrite tends to lower creep-resistance and stress-rupture values.[16] Moreover, in steels with sufficiently high-chromium content ferrite promotes the formation of the detrimental sigma phase, particularly when molybdenum, silicon, columbium, aluminum, or titanium are present.

Effects of Composition

In considering the effects of the individual alloying elements upon the crack sensitivity of weld deposits, it is important to differentiate between fully austenitic and partially ferritic structures. This has been dealt with in detail in a previous review.[2]

Thus, although the weld deposit may be satisfactory from the point of view of microstructure, individual effects introduced by some of the alloying elements may cause embrittlement. As long as sigma is not precipitated, molybdenum,[2, 4] manganese,[22, 107] nitrogen[2, 22] and carbon[2] are found to be beneficial, whereas columbium[2, 4] and silicon[2] are believed by most investigators to be detrimental. Columbium, for example, contributes to the formation of crater cracks. The detrimental effects of silicon may be counteracted by increasing the carbon content.[2] Larger quantities may again increase crack sensitivity. Some caution, however, is necessary. The elements which generally reduce crack sensitivity should not be added indiscriminantly. For each stainless grade there is an optimum amount at which an element acts most beneficially.

When fully austenitic weld deposits are required and, at the same time, crack sensitivity is an important consideration, nickel should be kept as near to the minimum as is necessary to make the deposit fully austenitic because an excess of nickel is believed to increase crack sensitivity. On the other hand nitrogen and manganese, in addition to the amounts required to produce fully austenitic weld deposits, are believed to reduce crack sensitivity still further, yet beyond a certain limit these elements may again act detrimentally.

Dilution may also affect crack sensitivity by changing the structure in the fusion zone of the weld deposit. In addition, a possibility that must be considered is that undesirable elements may be picked up from the atmosphere or from the slag.

Effects of Welding Technique

Improper adjustment of amperage, welding speed, and root gap may also affect weld-metal cracking.[17] Thus Carpenter and Jessen[193] stated that increases in current would promote the oxidation of the metallic constituent in the arc stream. Carpenter and Jessen[193] also suggested that a greater quantity of silicon would consequently be oxidized and this would result in a more severe, transgranular silicate film. Similarly, Thomas stated in his discussion[16] that, as the welding current is raised, weld-metal fissures tend to become more numerous and of greater size.

Welding speed and root gap merit consideration because they determine the thickness of the first layer. As the thickness is increased, the tendency toward longitudinal cracking in the center of the bead is diminished.

Effects of Weld Geometry

The shape of the groove is also of importance. Thus, concave-bead contours are more prone to cracking than convex deposits. It is generally believed that the thin, concave bead experiences shrinkages (stresses) of greater severity.[4]

Shrinkage stresses appear most severe in deposited root-beads of double vee-joints which are highly restrained. In varying welding technique, Gayley[171] reported the least amount of cracking when the root deposit was thickened by an oval motion of the electrode. This resulted in a wide convex surface, instead of the concave shape encountered in ordinary deposits. Moreover, Gayley found it advisable to retard the cooling rate by a continuous "making and breaking" of the arc and by building up the deposit.

Although these comments may be used as a guide, they may not be valid for all welding conditions. The human element still represents one of the most important variables. Thus, an experienced welder may and generally does produce weld deposits superior to those made by an inexperienced welder who closely follows a particular set of welding recommendations.

Dilution in the fusion zone which occurs on welding steels of compositions other than that of the electrode material may be either beneficial or detrimental. The subject will be discussed in detail in a future review.

Effects of Electrode Coating

Other variables are introduced by the types of electrode coating. For example, Thomas[4] stated that under equal conditions the titania-type coatings are more

likely to produce cracks in susceptible compositions than the lime-type coatings. However, this may also be related[214] to the differences in electrode composition and the effects of bead geometry. Thus the titania-coated electrodes may contain somewhat less chromium and produce weld beads which are less convex than those produced by the lime-coated electrodes.[2] In addition the titania-type electrodes deposit a higher oxygen content in the weld metal which will result in more severe microsegregations in the primary grain boundaries and, thus, will contribute to an increased-crack sensitivity.[204]

Whereas a partially ferritic weld deposit may be highly desirable in those applications which require tough and ductile welds, such structures may be unwanted when used in contact with strong corrosive solutions. This is of primary concern in the 18–8 (Cr-Ni) type grades which, when fully austenitic, seem to result in crack-sensitive weld deposits. However, the more highly alloyed 25–20 and 15–35 (Cr-Ni) grades, which give fully austenitic weld deposits, may give satisfactory service from both mechanical and corrosive viewpoints.

Careful study and control of the compositions of electrode core and coating should further reduce the crack sensitivity of fully austenitic weld deposits. Additional consideration of weld design, shrinkage, and residual stresses should also help to reduce unexpected cracking failures.

STRESS-CORROSION CRACKING

Stress-corrosion cracking introduces serious problems in many applications in which non-ferrous metals and alloys are used. For example, this is true of brass. In stainless steels stress-corrosion cracking is probably more common than is generally appreciated. It does occur in certain uses of heavily drawn articles, in some welded sections retaining severe residual and localized internal stresses, and other, often unusual, applications.

The susceptibility of wrought and welded stainless steels to stress-corrosion cracking depends upon the effects of several factors. They are (1) stresses in the steel, (2) the action of the corroding agent, (3) plastic deformation of the steel, (4) physical characteristics of the alloy and (5) length of exposure to corroding solution.

Stress-corrosion cracking, as the name indicates, is primarily caused by elastic-tensile stresses[149, 150] and the action of certain corrosive solutions. Thus, stress-corrosion cracking may occur without intergranular corrosion. Consequently, cracking may be in a transcrystalline or intercrystalline fashion. In the absence of intergranular carbide precipitation stress-corrosion cracking seems to occur almost entirely as transcrystalline fractures.[15, 152, 162, 176] However, in sensitized alloys the weakening effect of the carbide network may be responsible for intercrystalline fractures.[159]

Effects of Stresses

The elastic stresses may be of an internal nature or may be caused by external loads. Often, a combination of both will exist. Internal residual stresses are generally caused by fabricating, by welding (Fig. 22), or by rapid cooling from elevated temperatures as encountered in the usual heat treatments. Moreover, considerable stresses also exist in clad stainless steels and in welds made between dissimilar materials. They are caused by the differential thermal expansions. Forming and bending operations may also be responsible for serious residual stresses which, in favorable environments, cause stress-corrosion cracking.[162]

Fig. 22 Crack adjacent to weld in an 18–8 Mo (Cr-Ni-Mo) steel (0.05% C) caused by stress corrosion in strong alkaline solution. (Electrolytic oxalic acid etch.) Magnification 400 ×[16]

For identical steels the minimum stress necessary to cause stress-corrosion cracking also depends on the type of solution. For example, Type 347 stainless steels immersed in boiling 42% magnesium chloride required a minimum stress between 20,000 and 30,000 psi.[145] However, stresses as low as 7000 psi. have been found to be responsible for stress-corrosion cracking in 18–8 (Cr-Ni) stainless steels.[232]

Surface notches or pits[162] seem to increase susceptibility to cracking by reducing the amount of stress which is necessary to cause initial cracking. In fact Evans[158] suggested that stress-corrosion cracking is initiated by fracture of the surface film under stress.

Although it is generally appreciated that tensile stresses can cause stress-corrosion cracking, it still seems to be an open question whether or not compressive stresses may be dangerous.[233]

Effects of Corroding Agent

The agent may be either of liquid or gaseous nature. In liquid media, stress-corrosion cracking of austenitic stainless steels and weld deposits occurs only in certain types of solutions which generally contain chlorides[140, 149, 150, 156, 160, 162, 220, 224] or sulphides.[140, 157, 224] Chlorides are usually found to be far more dangerous than sulphides. Aside from solutions which contain chlorides intentionally, stress-corrosion cracking has also been experienced when chlorides were unintentionally present.[224] Stress-corrosion cracking has been also observed when these wrought and/or welded steels are employed in contact with concentrated alkaline solutions such as NaOH.[45, 52, 144] Thus, Wilton[205] reported that a lining of 18–8 (Cr-Ni) steel, which was exposed at 460 to 500° F. (240 to 260° C.) to a lubricating-oil distillate containing NaOH, failed after a service of two weeks. The lining had been manufactured by cold bending in a press followed by welding. No postheat treatments had been employed.

Stress-corrosion cracking may also be caused by certain gaseous environments in the presence of moisture.[153] Moreover, steam and hot water may cause cracking particularly when chlorides or sulphides are present.[87, 201, 202 233]

Brennert[233] suggested that the corrosive attack occurs under cathodic control, in so far as the environment must be sufficiently critical that (local) unstressed areas are cathodic whereas stressed areas are small and anodic. This conclusion is based by Brennert on his observation that when oxygen is released, stress-corrosion cracking does not occur.

So far it has been rather difficult to reproduce satisfactorily in the laboratory the service conditions existing in particular applications. Consequently, susceptibility to stress corrosion of a certain alloy is not easily determined for particular service requirements.

Effects of Deformation

In a very general way cold deformation in fully austenitic structures considerably enhances the susceptibility to stress-corrosion cracking.[140, 143, 144, 166] However, distinction should be made between the stresses set up within the steel and the increase in tensile strength which is due to work hardening.

The effects of work hardening on tensile strength are not believed[233] to be of consequence; instead the residual stresses, which remain after cold working, are of critical importance to stress-corrosion cracking. There seems to be some indication that a certain threshold-stress value exists below which stress-corrosion cracking does not occur.[233] However, little is known of this aspect particularly in regard to the effects of different degrees of cold work. Until reliable (quantitative) measurements are made, it would be difficult to make accurate predictions.

As tensile strength has been accepted as giving an indication of the degree of cold deformation, the user of cold-rolled steels for aircraft construction has been limited in England to a maximum of 157,000 psi. This, however, seems unduly severe, as various investigators report that they have not been able to observe stress-corrosion cracking in materials cold-worked to tensile strength of 180,000 psi.[166] or even 225,000 psi.[167] The actual limits, of course, depend upon the corrosive environment.

Effects of Austenite Stability

Additional factors have to be considered in those compositions where part of the austenite, existing at room temperature, is not stable; i.e., where, if conditions of equilibrium were met, a greater amount of ferrite would be present at room temperature. The effects, however, will vary among the different solutions.

The results obtained by Rocha,[143, *] who used caustic soda solutions containing sodium sulphides on various alloys, are shown in Fig. 23. These results

* Rocha's hypotheses however require additional experimental confirmation. For example, experiments on the susceptibility to stress-corrosion cracking of different austenitic steels in steam and hot water have given results which disagree with Rocha's results and theories.[224]

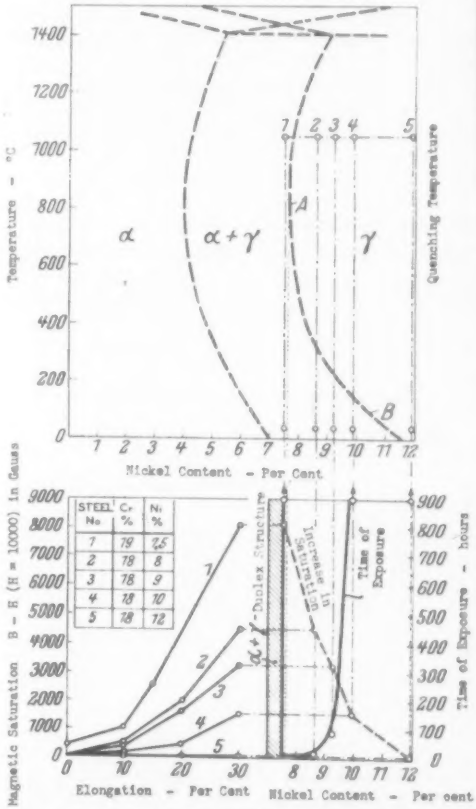


Fig. 23 Relation between stability of austenite and the susceptibility of 18–8 (Cr-Ni) type steels to stress corrosion cracking[143]

suggest that in alloys quenched from 1920° F. (1050° C.) the resistance to stress corrosion decreases as the metastability of the alloy increases. Rocha interpreted this to mean that "structural supersaturation" may produce effects which are similar to actual deformation.

Cold deformation as long as it tends to approach this equilibrium by enhancing the transformation of austenite into ferrite would then be likely to be somewhat beneficial in reducing sensitivity to stress corrosion.

This was also pointed out by Rocha[143] whose illustration is repeated in Fig. 24. Rocha's specimens were exposed to calcium chloride solutions under stresses of 28,000 psi. In a fully stable austenitic composition containing 12% nickel, susceptibility to stress-corrosion cracking increases with cold work. In the alloys of lower nickel content where cold work causes transformation of some austenite into acicular ferrite, the tendency for stress-corrosion cracking is reduced by this deformation.

Rocha[143] believed that the reasons for these effects are of a chemical nature. Preferential solution of the ferrite patches appears to reduce the susceptibility to stress-corrosion cracking.

Two additional factors should also be considered. First, the higher the crack sensitivity of the austenitic stainless steel the lower is the minimum stress required to cause stress-corrosion cracking. Secondly, the faster the chemical solution rates of the metal along the cracks the more serious are the effects of stress corrosion.

Effects of Composition

The individual alloying elements seem to affect the susceptibility to stress-corrosion cracking in two ways. Their action may be ascribed either to their effects on the crack sensitivity (particularly in weld deposits) of the matrix or to their ability to stabilize austenite at room temperature. Those elements which increase the crack sensitivity also may be assumed to increase the susceptibility to stress-corrosion cracking. On the other hand austenite stabilization is beneficial. However, once a stable, fully austenitic structure is obtained at room temperature, excessive additions of the austenite former may again be detrimental. For example, in fully austenitic compositions excessive quantities of nickel, which increase crack sensitivity, are reported to enhance the tendency toward stress-corrosion cracking and to be most detrimental in amounts of 25% nickel.[143]

Copper also improves austenite stability at room temperature. Thus, the addition of 1 to 3% copper to 18–8 (Cr-Ni) steels considerably improves the resistance to stress-corrosion cracking.[194] This is highly important in cold-worked stainless sheets and wires which remain fully austenitic at room temperatures (18% Cr, 9% Ni, 3% Cu).

Carbon, in solution, is claimed[144] to increase the tendency to stress-corrosion cracking. The causes are believed to be due to the precipitation pressure of carbon.[144] In general, Uhlig,[178] however, finds that sensitivity to cracking increases up to 0.045% carbon, but decreases again with a higher carbon content.

Molybdenum, which is known to reduce crack sensitivity, also greatly reduces susceptibility to stress-corrosion cracking.[180, 234] In fact, in many applications which may cause stress-corrosion failures when ordinary 18–8 (Cr-Ni) steels are used, such failures are prevented by the use of molybdenum-bearing stainless steels[233, 234] or welding electrodes.

Stabilized columbium- or titanium-bearing grades, in which the prevention of intergranular-carbide formation precludes intergranular cracking, nevertheless, offer no assurances that under proper stress and corrosive conditions transcrystalline stress-corrosion cracking will not develop.[162] In fact, the columbium-bearing grades seem more susceptible than most of the common grades.

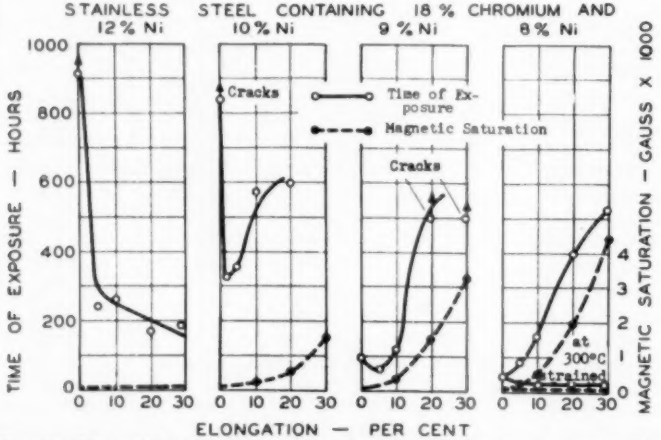


Fig. 24 Effect of ferrite content upon the susceptibility to stress corrosion cracking at a load of 28,400 psi.[143]

Reduction of Susceptibility

Several treatments may reduce the susceptibility of stainless steels to stress-corrosion cracking. First, the crack sensitivity of the stainless steels itself could be lowered;[143] secondly, suitable heat treatments that reduce the residual stresses could be utilized;[162] and finally, the composition could be adjusted, particularly by the addition of molybdenum which until now has

proved to be the most reliable commercial practice.[233]

As tension stresses seem prerequisite for stress corrosion, the introduction of compressive surface stresses by peening may seem desirable. However, considerable caution is required for, as Evans[154] points out, "where localized corrosion or cracking is due to residual stresses of a localized character, peening will ameliorate; but where compressional stresses are already present, such treatment may sometimes make matters worse."

It is likely that many of the failures in wrought and particularly in welded stainless steels which are now either overlooked or ascribed to other effects are caused by stress-corrosion cracking. Thus, careful examinations of a number of failures, ascribed to other causes, might show them to be cases of stress-corrosion cracking. A combination of conditions must usually be present for stress-corrosion cracking to occur in a steel. Stresses must be present either as residual stresses resulting from fabrication or welding operations or as applied stresses resulting from external pressures or thermal gradients. In addition, a suitably corrosive environment must also exist. Under these conditions, either the use of compositions which characteristically exhibit a low susceptibility to stress-corrosion cracking or special heat treatments may be advisable.

SHRINKAGE, DISTORTION, AND RESTRAINT

The chromium-nickel stainless steels are characterized by a higher electrical resistance, lower thermal conductivity, and greater thermal expansion than the ordinary mild steels.[14, 212] Because of these properties the austenitic steels show a greater tendency toward shrinkage and distortion than do the carbon steels and the chromium stainless steels.[137, 168] Particularly in heavy castings[113] and in welds these factors, under severe conditions, may cause serious residual stresses or even cracking. For example, severe shrinkage stresses caused by joining light and heavy sections are often responsible for cracking.[141] Careful control of the cooling rates is beneficial and may help to prevent cracking.

Distortion is also of consequence in the welding of thin (below $^1/_4$ in.) stainless sheets. Here best results are obtained by the use of tightly clamped fixtures. Moreover, the spacing between the sheets should be about one-half the thickness of the sheet.[168] Flanged joints should be set up without spacing.[168] However, tight clamping, although it minimizes distortion, may also introduce disadvantages. Thus, in welds, as is true in castings,[182] hindered contraction may cause cracking. This is particularly characteristic of heating and cooling cycles associated with steep thermal gradients.

In joining thin sheets, resistance seam welding techniques are superior to fusion welding, because fusion welding causes greater distortion.[182]

In resistance welding lap welds are superior to butt welds particularly when joining thin sections to thicker ones. Stress concentrations in the thinner piece are more serious in butt joints, and may lead to failure in service.[182]

When possible, jigs should be used which embody a cooling apparatus to absorb excess heat as rapidly as possible.[107, 118] Thus, prior to welding, joints are often "backed up" by a copper backing strip, which preferably should be water cooled. Sometimes damp rags are laid inside the corners of the containers.[107]

When possible, corner joints should be used as they, because of their natural rigidity, help to decrease distortion. Welding stiffeners, applied by a few short tack welds, also offer advantages, particularly when welding long seams or when it is difficult to set up adequate jigs.[168] However, care should be taken that tack welds are not longer than necessary, and that they are completely fused.[169] If too much weld metal is deposited, the stiffeners may be responsible for worse distortion.[107]

Control of Shrinkage

Because shrinkage is closely related to cracking, its control is highly important. As the initial root deposit is most susceptible to cracking, slow cooling rates are extremely desirable in order to keep the deposits in the plastic-temperature range as long as possible. The subsequent deposits should be smaller and laid more rapidly. Ordinarily, however, standard beads are satisfactory. If difficulties arise, particularly when welding heavy sections, special techniques such as cascading or back-stepping may be used. In certain cases, even preheating may be beneficial.

Peening is sometimes used to change the residual-stress pattern after forming and welding.[157] In most cases, however, it seems doubtful that the small advantages gained offset the costs of the peening operation. In fact, excessive peening may be harmful. This is particularly true for stainless steels which are susceptible to sigma formation. Peening, as well as other cold-working processes, considerably increases the rates of sigma formation.

Effect of Bead Contour

Fatigue tests by Harvey and Campbell[126] indicated that the fatigue life decreased considerably whenever there was an abrupt change of section on a sharp radius at the foot of the weld bead. Their tests on arc- and oxyacetylene-welded beads showed that the oxyacetylene beads had a more gradual slope.

However, in the light gages tested, the arc welds showed higher tensile strengths and ductility than oxyacetylene welds. No such merits occurred when the weld deposits were subjected to vibrating stresses, where the maximum bending moment is at the foot of the weld. In the case of heavier gages (above $^1/_4$ in.) oxyacetylene welding would not be as satisfactory as arc welding.

Hindered Contraction

Hindered contraction stresses may become particularly severe. They are believed to be the primary cause of thermal fatigue which describes the failure by cracking that occurs when repeated heating and cooling cycles are involved. If in a heating or cooling cycle the (thermal) stresses do not exceed the elastic properties of the steel and plastic flow does not result, failures which are due to thermal fatigue are not likely to occur. However, when appreciable plastic flow occurs as a result of each heating cycle, failures may occur when the material lacks the ability to deform without cracking during the cooling cycle.[93 132 163] The effects of hindered contraction of heat-resistant castings are shown in Fig. 25 for 25–12 and 25–20 (Cr-Ni) alloys of the following composition:

	Alloy A %	*Alloy B* %	*Alloy C* %	*Alloy D* %
C	0.45	0.32	0.32	0.20
Mn	0.54	0.48	0.53	0.92
Si	0.60	0.63	0.50	1.36
Ni	12.8	13.2	11.5	21.0
Cr	26.8	23.9	26.2	24.2
N	0.08	0.09	0.07	0.154

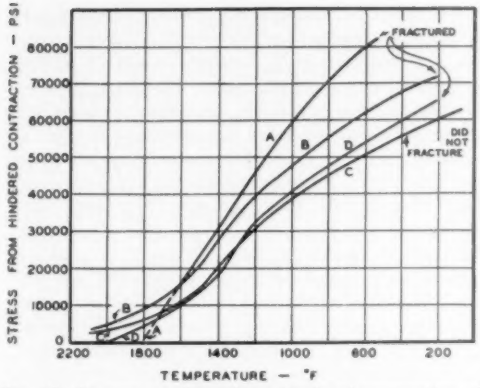


Fig. 25 Stresses resulting from hindered contraction of 25–12 and 25–20 (Cr-Ni) stainless castings[132, 163]

GRAIN SIZE

As a major structural transformation does not occur in the austenitic chromium-nickel stainless steels, grain refinement can be accomplished only by cold work followed by recrystallization. The final grain size, therefore, depends upon the amount of deformation, the composition and the temperature and time of the annealing heat treatment. These various factors have been discussed at length by Vialle.[123]

Fully austenitic structures experience noticeable grain growth after being heated above 1900° F. (1040° C). The degree of grain growth will become appreciable after the chromium carbides have dissolved above 2000 to 2200° F. (1095 to 1205° C.).

Effects of Alloying Elements

Alloying elements may modify the extent of the grain growth. Thus, the carbide-forming elements columbium, titanium, tantalum, and tungsten, as will additional chromium and carbon, retard the grain growth of austenite until the temperatures are reached at which these carbides go into solution.[10] Similar considerations seem to hold true for nitrides. Small amounts of aluminum also produce considerable grain refinement. An aluminum content of about 0.02 to 0.03% is thought to be the most effective. On the other hand Gulyaev[10] stated that the elements nickel and cobalt which are soluble in the fully austenitic matrix have no effect on the grain size of the austenite.

Silicon seems to promote grain growth of the austenite above about 1850° F. (1010° C.). This is based on observations by Newell[98] who observed the effects of heating 18–12 (Cr-Ni) alloys which contained less than 0.08% carbon and 2.0 to 3.0% silicon.

The effects of annealing temperature and composition as reported by Vialle are shown in Table 9.[123] Increases in the carbon content considerably reduce the amount of grain growth. The addition of small amounts of aluminum to alloy No. 6 considerably inhibited grain growth. Without the presence of aluminum, alloy No. 6 would have shown the largest grain size—probably ASTM Size 1 at 2190° F. (1200° C.). Titanium additions seem to be even more effective than aluminum in inhibiting grain growth (alloys Nos. 7 and 8). Moreover, titanium carbides are not likely to

Table 9—Effects of Annealing Temperatures for ½ Hr. on Grain Size of 18–8 (Cr-Ni) Stainless Steels[123]

Alloy No.	*Composition* C	Si	Mn	Cr	Ni	Ti	Al	*Grain size 2010° F. (1100° C.) 1000 sq. microns*	*Corresponding ASTM No.*	*2100° F. (1150° C.) 1000 sq. microns*	*Corresponding ASTM No.*	*2190° F. (1200° C.) 1000 sq. microns*	*Corresponding ASTM No.*
1	0.10	0.61	0.26	17.98	8.10	...	...	5.7	5	13.3	3	33	2
2	0.11	0.87	0.28	18.02	7.97	...	...	2.5	6	4.8	5	12.2	3
3	0.15	0.37	0.33	16.98	8.01	...	...	3.1	5	4.8	5	11.9	4
4	0.15	0.34	0.62	16.89	8.23	...	...	2.3	6	2.3	6	3.2	5
5	0.095	0.48	0.40	17.38	8.52	...	...	4.3	5	10.6	4	22.5	3
6	0.075	0.48	0.39	17.34	8.16	...	Trace	2.6	6	4.1	5	7.7	4
7	0.090	0.96	0.22	18.40	7.90	0.18	...	0.7	8	2.3	6	6.9	4
8	0.090	1.18	0.60	16.63	7.86	0.25	...	0.5	8	0.5	8	Not determined	...

be as stable at elevated temperatures as the submicroscopic aluminum oxides.

In alloys containing some ferrite in the austenitic matrix, grain growth will be retarded by the duplex structure.

Effects of Mechanical Properties

At *room temperature*, a fine grain size will give higher yield, tensile and fatigue strengths than a coarse grain size. Impact toughness is generally higher in fine grained austenitic alloys,[95] whereas elongation is somewhat lowered. Such results were shown by Habart and Caughey[83] for a fully austenitic alloy containing:

	%
C	0.07
Mn	0.46
Si	0.55
P	0.007
S	0.009
Ni	8.62
Cr	18.80

Their results on different mechanical tests on annealed and quenched alloys are repeated in Tables 10 and 11. As the authors point out, it should be remembered that most stainless steels will have a grain size in between the extreme conditions used in this test. Service performances also indicated preference for a small grain size and some users of austenitic stainless steels specify a maximum grain size of about 5 or 6.

Not all of these considerations seem to hold true at *elevated temperatures*. Thus various authors[89, 99, 111, 133, 146, 180, 247] report that a coarse-grained structure possesses higher tensile and creep strengths at temperatures of 1000° F. (540° C.) and above, than is found in fine-grained alloys. On the other hand at elevated temperatures ductility decreases as the grain size is increased.[89, 146, 180, 251] Impact and, possibly, fatigue strength are also reduced by grain coarsening.[94]

Table 10—Effects of Grain Size on Mechanical Properties of Fully Austenitic Stainless Steels[83]

Properties	*Fine grain, ASTM size 5 to 7*	*Coarse grain, ASTM size 0 to 1*
Yield strength, psi. (0.5% stretch)	39,350	32,370
Tensile strength, psi.	99,390	90,950
Elongation, in 2 in.	71.6	76.3
Brinell hardness	166	156

Table 11—Effect of Grain Size on Endurance Limit (Rotating Beam)[83]

Type	*Stress, psi.*	*Cycles*	*Remarks*
Fine grain, ASTM size 5 to 7	±42,000	29,000	Failed
	±40,000	71,700	Failed
	±39,000	10,259,100	No failure
	±38,000	10,013,500	No failure
Coarse grain, ASTM size 0 to 1	±35,000	92,300	Failed
	±34,000	10,015,400	No failure
	±33,000	10,004,000	No failure
	±32,000	10,000,000	No failure

As the temperature decreases below 1000° F. (540° C.), the finer-grained structures become stronger than the coarse-grained steels.[180] However, with an increase in testing time the coarse-grained alloys begin to exhibit a higher rupture strength.[180]

Effects on Sigma Phase

There is some indication that alloys, which are susceptible to sigma precipitation, exhibit slightly superior properties when they have a large grain size. Thus Clark and Freeman[89]* indicated that sigma precipitation in fine-grain steels causes a greater degree of embrittlement, in spite of the fact that the fine-grained alloys showed the greater ducility at elevated temperatures.

These observations may well be explained by the fact that a coarse-grained steel exhibits greater resistance to sigma formation than a fine-grained steel. This is due to the fact that sigma tends to form predominantly at the grain boundaries. Consequently, any diminution of grain-boundary area will result in a reduced amount of sigma precipitation.[238]

Effects on Intergranular Corrosion

Alloys susceptible to intergranular corrosion benefit by a small grain size because a small grain size retards the severity of sensitization on short exposure times in the sensitizing-temperature range.[80, 117, 146] The reason is that fine-grained steels have a greater grain-boundary area. This reduces the amount of carbide precipitation per unit area and decreases, in turn, the degree of chromium depletion.

Grain Structure in Weld Deposits

Austenitic weld deposits tend to form extremely large columnar grains. This is even true when many beads are deposited. Thus, each new weld bead continues the grain structure of the previous, solidified deposit, Fig. 26.

Although this does not affect the tensile properties in the longitudinal direction, the elongation in the transverse direction is considerably reduced. This is indicated in results by Gayley[171] on 25–20 (Cr-Ni) weld metal. Such directional effects upon ductility suggest that tests for weldability would also be affected. Thus, the habit of crystallization represents a factor which has some bearing upon the weldability characteristics.

Grain refinement of weld deposits may be produced by hammering or shot-peening the deposit either when it is hot or cold. It is also apparent from Fig. 27 that these treatments prevent columnar-grain structures.[91, 171]

Of course, the cold working must have been of sufficient severity to allow recrystallization to occur and

* Clark and Freeman do not actually analyze the precipitate beyond classing it as an "unidentified phase." However, it is likely that this phase is sigma which appears in addition to small ferrite patches in most of their alloys. See also references.[99, 172, 191]

to extend below the normal depth of penetration of the arc during the process of depositing the next layer.[171] The effects of insufficient working of the first four layers are evident in Fig. 27.

These working techniques, however, do not seem to improve the mechanical properties of the stainless steel materially.[171] Thus, in weld deposits grain refinement is rarely practiced.[91]

In general, grain size of austenitic stainless steels is rarely responsible for service failures. Thus, the grain structure represents a minor variable in most applications. Only in a few isolated cases would grain control be warranted to obtain certain particular properties, characteristic of either a fine or coarse grain structure. One application of this kind is in oil-refinery tubes of 18–8(Cr-Ni) grades where long experience shows that the best service is secured from fine-grained tubing. Such an application involves long heating within the carbide-precipitation range. There are considerable variations in the exact temperature at which the tubes are used. It is usually below 1250° F. (675° C.), except in cases of inadvertent overheating. It has become usual practice to specify fine-grained tubing (ASTM size 6 to 8) which has been given a stabilizing anneal after the cold work required to finish the tubes.[46]

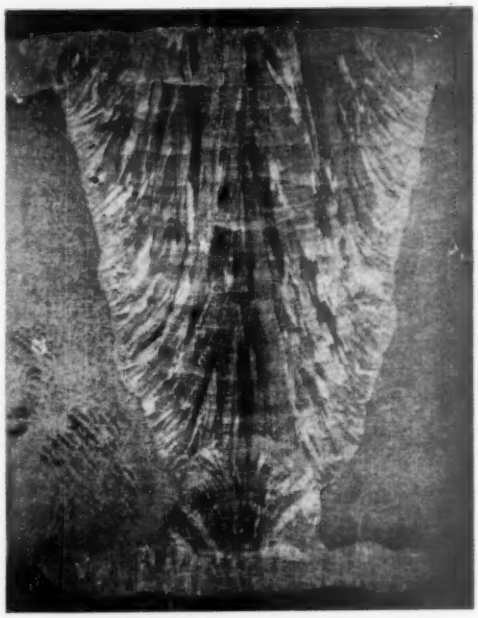


Fig. 26 Weld in 60-lb. high yield steel. 10% acid ferric chloride etch. Magnification 2 ×[171]

EFFECTS OF COLD DEFORMATION

Although the austenitic stainless steels cannot be hardened by heat treatments, they can be hardened by cold work. As work hardening occurs quite rapidly, more rapidly than in the ferritic chromium stainless steels, intermediate annealing treatments are generally necessary. Moreover, the lower the chromium-nickel content the more readily does the stainless steel work harden.[54, 126, 139, 173, 221]

When the (metastable) austenitic composition is cold worked, some of the austenite tends to transform into ferrite.* For example, Mitchell[139] reported obtaining 9% ferrite after cold reducing an austenitic composition by 50%.

The ferrite that forms is magnetic and, thus, can be determined by magnetic means.[91] This may be utilized commerically as, for example, in the manufacture of certain types of wires used in magnetic wire-recording apparatus.[119] The wire is severely cold drawn. This results in a dispersion of magnetic ferrite particles, which are long in relation to their cross section, in a nonmagnetic austenite matrix.

The amount of ferrite that forms depends upon four major factors.[6] These are: (1) degree of deformation, (2) temperature, (3) composition, and (4) rate of deformation. Temperature and rate of deformation are very much interrelated.

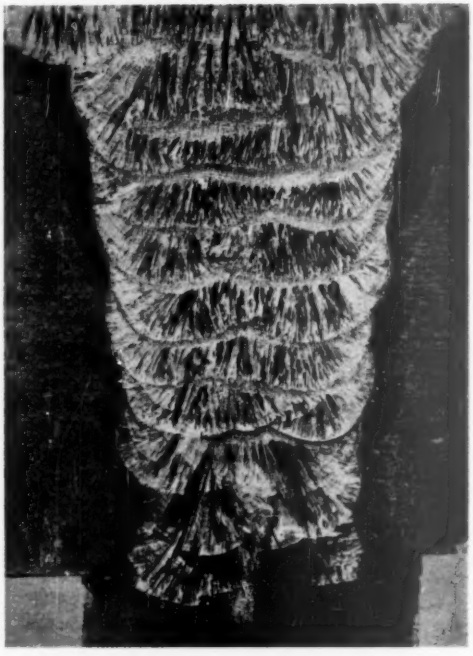


Fig. 27 Macrograph of Type 310 weld metal deposited in 2-in. plate peened after each pass. Magnification 2 ×[171]

* Actually an acicular (pseudomartensitic) type of ferrite supersaturated with carbon will form on transformations of the austenite below 400° F. (205° C.). Although its lattice is that of α-ferrite, it is harder than the austenitic matrix.

Degree of Deformation

The greater the degree of deformation the greater is the amount of ferrite which transforms from the austenite. Moreover, as the amount of deformation is increased, tensile and yield strengths will increase, whereas ductility will decrease.[55, 86]

Effect of Temperature

At each particular temperature, a maximum amount of ferrite may form. This amount cannot be increased by further deformation. Decreasing the temperature will reduce austenite stability, which may then cause the formation of additional ferrite. Actually, two effects can be ascribed to temperature. A direct temperature effect will change the mechanical properties, whereas a secondary temperature effect tends to cause structural changes in the metal during the process of deformation.[69]

Effect of Composition

The composition of the stainless steel determines the stability of the austenite. This was shown by Houdremont[15] who measured by magnetic means the amount of ferrite which had formed from the austenite at various degrees of cold rolling for several alloys. Thus, although 18–8 (Cr-Ni) compositions may exhibit a noticeable amount of transformation, 18–10 or 12–12 (Cr-Ni) alloys showed negligible amounts. The effect of chromium, molybdenum, nickel, manganese, and carbon on austenite stability is illustrated in Fig. 28.[54]

Generally, those elements which increase austenite stability will decrease the rate of cold work hardening. This is usually desirable as it allows a greater amount of cold work to be performed before annealing may become necessary.

Raising the nickel and/or manganese content will increase the stability of the austenite. Similar effects are produced by nitrogen.[60] The effects of the carbon content are still a matter of disagreement. However, most of the evidence indicates that the higher the carbon content the more rapidly does work hardening occur.[66, 215, *] Thus, effects of carbon differ from the other austenite formers—nickel, manganese, and nitrogen.

Molybdenum[82] and chromium,[2, 48] although acting as ferrite formers at elevated temperatures, also seem to increase austenite stability at room temperature up to a combined content of Cr + 1.5 Mo = 20%, Fig. 28.[54] Chromium is particularly beneficial in alloys with less than 12% nickel, since increases in the chromium content decrease cold-work-hardening characteristics. On the other hand, above 14% nickel, chromium seems to increase the cold-work-hardening effects slightly.[60]

Bloom, Goller, and Mabus[60] studying the cold-work-hardening properties of stainless steels in compression observed that the greater the austenite stability the less work was required to cold upset the material.

Rate of Deformation

The rate of deformation or straining is closely related to temperature. Thus, as the rate increases, more heat will be developed in the material. This, in turn, increases the austenite stability and allows less austenite to transform into ferrite. For example, Montoro and Hugony[18] showed by X-ray diffraction studies on 18–8 (Cr-Ni) wires that, as the rate of straining was increased, a smaller amount of alpha ferrite formed from the austenite than would have formed if slower straining rates had been used.

If the greater amount of heat generated by the more rapid rates of straining could be absorbed or removed so that the steel would remain at constant temperatures, then the effects of the deformation rate would be very small.[222]

The rate of deformation is of particular significance in testing and cold-fabricating operations where the increase in temperature, which is due to the higher rate of straining, tends to lower the strength and the ductility of the material. Thus, various authors have shown quantitatively in performing tensile tests on stainless steels that, as the rate of straining is reduced, tensile strength and elongation are increased.[11, 27, 30, 66, 70, 222] This does not occur in carbon steels because in these steels cold working does not produce a structural change. Thus, in carbon steels the strength increases with the rate of straining.[27, 50] Elongation in carbon steels, as might be expected, decreases with rates of

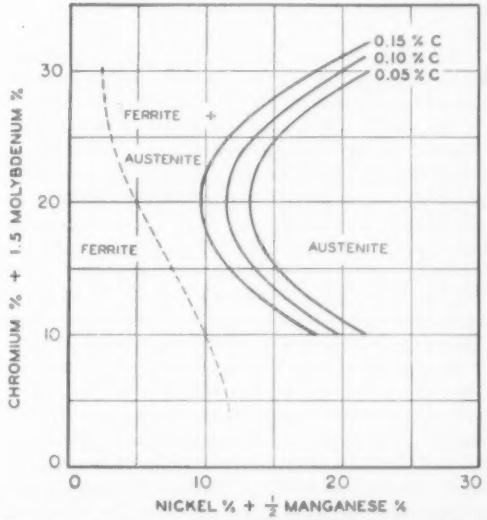


Fig. 28 Stability of Cr-Ni austenitic stainless steels as determined by (Chromium % + 1.5 Molybdenum %), (Nickel % + 1/2 Manganese %), and Carbon Balance[54]

* The opposite opinion has been reported by Parmiter[173] and Scharschu.[218]

straining. This is also true in stainless steels where the decreases are more severe.[59]

The stress-strain relations of any metal are strongly influenced by two distinct factors, the rate of straining and the temperature at which the test is conducted.[60] However, in stainless steels because the strain-rate factor includes its own temperature effect, the testing temperature may be raised with increases in the rate of straining. The greater amount of "hard" acicular ferrite, forming at the reduced rates of straining, results in a higher resistance to deformation and, consequently, in a higher tensile strength. Moreover, as less heat is developed in the material, the elongation is higher.

Effects on Carbide Precipitation

It was stated earlier that cold work followed by an immunizing heat treatment between 1350 and 1550° F. (730 and 845° C.) considerably reduces susceptibility to intergranular corrosion. This treatment, however, offers disadvantages particularly when further cold fabrication is desired. This is because the steel is only partially softened in the immunizing-temperature range.[60] Further fabrication would necessitate higher annealing temperatures. This would make the alloy again susceptible to further intergranular precipitation.

Effects on Mechanical Properties

The mechanical properties which result from the cold working of metastable austenitic compositions are a combination of the effect of work hardening and the transformation of some austenite to acicular ferrite. It should be remembered that, although cold work tends to enhance ferrite formation, at each particular temperature only a certain definite amount of ferrite can form.

The effects of straining at room and at subzero temperatures are shown in Fig. 29.[246] Whereas magnetic tests revealed that straining at 80° F. (27° C.) did not cause transformation to acicular ferrite, at −110° F. (−80° C.) and −320° F. (−195° C.) considerable quantities of ferrite were formed. Thus, the effects of straining at 80° F. (27° C.) on the Brinell hardness values and on the Izod impact toughness (tested at −295° F. (−180° C.) were caused by work hardening. However the effects of straining at −110° F. (−80° C.) and at −320° F. (−195° C.) on these mechanical properties are caused by both strain hardening and the austenite-acicular ferrite transformation.

The mechanical properties, which are ordinarily listed, pertain to the majority of compositions in which no significant ferrite transformation occurs on deformation or straining at room temperature. However, should considerable amounts of austenite transform into ferrite, then almost all of the mechanical properties will be appreciably affected.

Cold work considerably increases the *tensile strength*. Thus, severely deformed materials may exhibit tensile

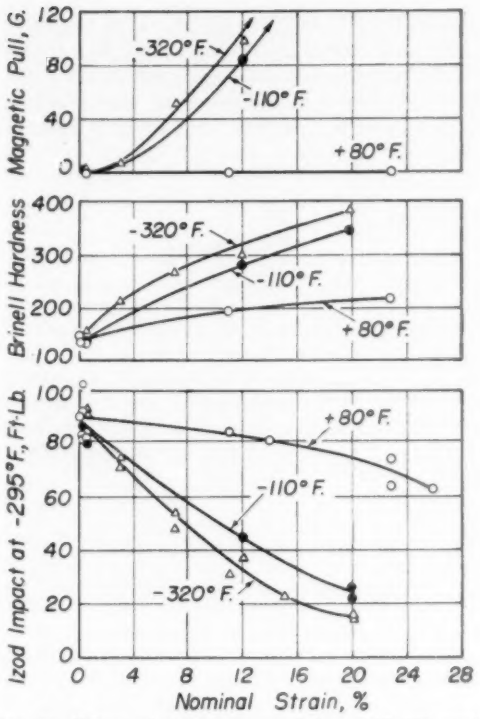


Fig. 29 Effects of straining annealed 18-8 (Cr-Ni) steel (Type 304). Straining temperatures are indicated on the curves[246]

strengths as high as 200,000 psi.[104, 105, 128, 138]

The relatively low *elastic limit* of annealed grades, amounting to about 15,000 to 25,000 psi., and the *yield strength* (0.2% offset) of about 35,000 to 45,000 psi. are increased to an even greater degree than the tensile strength.[104, 105] Severe cold work may increase these values by a factor of two to four, depending upon the grade. On some mills it is possible to increase the yield strength by a factor of five.[216] A higher elastic limit is often desired for many structures which are subjected to high stresses.

The *ductility* is progressively reduced with cold work. Thus, severe deformations may give trouble in heavy-forming operations.

Impact toughness is also lowered with increasing cold deformation,[35] however, to a lesser degree than the ductility. Thus, severe cold work may reduce the Izod impact toughness from a range between 100 and 130 ft.-lb. to between 25 and 75 ft.-lb. These values are still sufficient to allow for severe abuse in handling.[128]

The *modulus of elasticity* is found to be somewhat lower in the cold-worked than in the annealed condition. This is particularly true in the direction of rolling.[104]

The *fatigue* strength may be raised from 35,000 to 40,000 psi. to 60,000 to 85,000 psi. by severe cold defor-

mation.[128] Lebert,[138] however, reported that cold deformation did not affect fatigue strength.

Effects on Fabrication

Because of the rapid rate of work hardening of stainless steels, most cold-forming operations require more power than is required for the ferritic stainless and the lower alloy steels. For cold-rolling operations the effects of different reductions on the resistance to deformation of a carbon steel and a stainless steel are shown in Fig. 30.

The steels were of the following composition:

	Mild steel %	*Stainless steel* %
C	0.12	0.13
Mn	0.34	0.35
Si	0.14	0.41
Cr	0.30	18.3
Ni	...	8.55

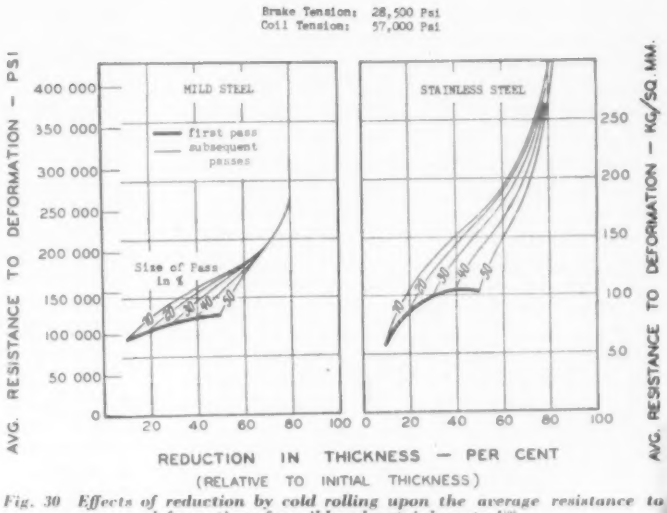


Fig. 30 Effects of reduction by cold rolling upon the average resistance to deformation of a mild and a stainless steel[139]

The resistance-to-deformation of both steels, which differs for the initial passes, ultimately approaches a single line. Thus, after a reduction of 60% of the carbon steel and 80% of the stainless steel it would be immaterial to further rolling operations if the initial reductions were made in one or several passes. In both steels the average resistance-to-deformation increases with each pass. However, the increase is considerably more severe for the stainless steel than for the carbon steel.

Ductility is also considerably reduced by cold deformation. These two factors may make intermittent annealing treatments desirable; otherwise, deep-forming and severe-spinning operations may cause breakage in the stainless steels or the forming tools.

In the stainless grades which may form appreciable quantities of ferrite during cold-fabricating operations, such as the 301 Type,* retarding ferrite transformation by warm drawing may, in certain cases, be advantageous.[123] For example, Aborn[124] reported that working at 570° F. (300° C.) retarded ferrite transformation of an 18–8 (Cr-Ni) (0.10% C) considerably more than working at room temperature did. Moreover, several times as much energy was required to apply an equal deformation to the stainless steel at room temperature as compared with the energy required at 570° F. (300° C.).

In many structures the use of cold-worked stainless steel parts is desirable because of the high elastic limit and the high ultimate strength. In the cold-worked condition these properties may be utilized by allowing a decrease of the section size and the weight of the structural member.[124] Most desirable are the 17–7 (Cr-Ni) compositions because the stainless alloys work harden most readily. Higher alloy content will require greater cold reduction to obtain a given tensile strength. This is undesirable because of a greater loss in ductility.[130]

Discussion of the various fabricating operations is beyond the scope of this report. A number of good articles on spinning[121] and machining[129] and other fabricating processes[114] are already in the literature.

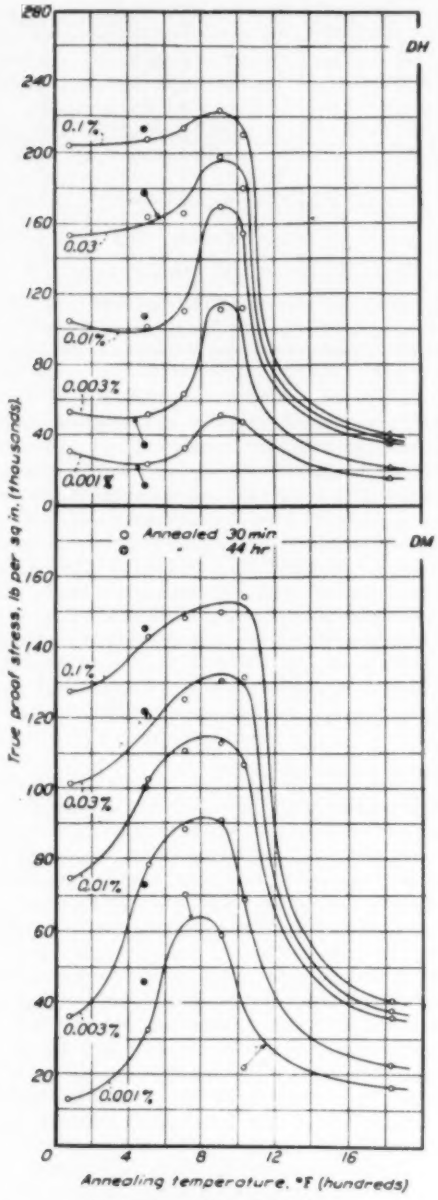
Effects of Prestraining

Slight prestraining of a *cold-worked* metal having high internal stresses tends to reduce these internal stresses. In this manner the effects of prestraining may be compared to those produced by annealing.[122] On the other hand, slight prestraining of a *fully annealed* steel tends to increase internal stresses to a high value.[122]

Prestraining of cold-worked stainless steel sheets and plates also raises the elastic limit. This was shown in detail by McAdam and Mebs[121, 122] for 18–8 (Cr-Ni) alloys in which the elastic strengths, as indicated by proof stresses, were increased considerably by slight prestraining. Annealing for 30 min. at 900 to 950° F. (480 to 510° C.) for the relief of internal stresses produces additional increases in the elastic strength, Fig. 31. These increases are particularly noticeable in steels prestressed only 0.001 and 0.003%. Little difference was observed by McAdam and Mebs[122] in the effects of longer stress-relieving periods at lower temperatures. This is indicated in Fig. 31, for periods of 30 min. and 36 hr., respectively, at 480° F. (250° C.).

* 0.08–0.20% C, 16–18% Cr, 6–8% Ni.

Similar results were reported at −110° F. (−79° C.), where the tensile-elastic properties were found to be higher than at room temperature.[112] No conclusions can as yet be drawn on the effects of prestraining on the fatigue and impact properties at subzero temperatures.



18-8 chromium-nickel steel DH, hard.
18-8 chromium-nickel steel DM, half-hard.

Fig. 31 Influence of annealing temperature upon proof stress of 18–8 (Cr-Ni) stainless steel cold drawn and annealed at indicated temperatures[122]

At times it is desirable to induce prestraining only in the surface layers of sheets. This is generally accomplished by a final light pass of the fully annealed sheet through the rolling mills.

Thus, skin rolling has been found to be beneficial in reducing susceptibility to surface deformation which is caused by scratching or wrinkling during handling or fabricating operations. It has been suggested that stainless steels with tension stresses in a 0.005-in. deep skin may be of advantage for airplane wing construction.[130]

Somewhat similar effects may be produced by shot peening. This process, in addition to introducing compressive stresses in the surface, tends to smooth out small surface irregularities. The combination of these two effects increases the fatigue life of many structural members. Shot peening has been found particularly useful in lengthening the life of stainless springs.[179]

Subsequent to peening the stainless surfaces should be cleared of all adherent (minute) steel particles from the ordinary carbon-steel shot. Otherwise rusting of the stainless surface may occur in environments favorable to corrosive attack.

Stress Relieving

The greatest advantage of stress relieving cold-worked stainless steels is the improvement in the elastic properties. Treatments consisting of 30 min. to 2 hr. at 650 to 800° F. (345 to 425° C.), followed by air cooling[126] are generally recommended. However, complete stress relieving is accomplished only by annealing between 1350 and 1450° F. (730 and 790° C.).

Because internal stresses increase the tendency toward carbide precipitation,[91] stainless grades susceptible to such carbide precipitation should not be stress relieved for more than 2 hr. at temperatures above 800° F. (425° C.). For complete stress relieving immunization heat treatments may have to be used.

Temperatures below 800° F. (425° C.), in many instances, are insufficient to give satisfactory relief of internal stresses.[105] Nevertheless, such a treatment produces some beneficial effects. For example, Franks and Binder[104] showed that heating cold-worked 18–8 (Cr-Ni) stainless steels at 390° F. (200° C.) followed by air cooling raises the elastic limit somewhat, in addition to improving fatigue strength and impact toughness slightly.

At these temperatures, the beneficial effects gained from long holding periods seem questionable, although they are often recommended. This is indicated by data by McAdam and Mebs,[122] as shown in Fig. 31.

Quenching Stresses

Wrought steels, as well as castings and weld deposits, which are quenched or rapidly cooled from high temperatures, usually contain residual stresses of considerable magnitude. Experiments by Glikman and

Tekht[136] on wrought 18-8 (Cr-Ni) disks* which were quenched in cold water from 1920° F. (1050° C.) showed that the tangential stresses† varied uniformly from a compression stress of 34,000 psi. at the outside to a tensile stress of 34,000 psi. at the inside. The radial tensile stress at the middle of each disk amounted to about 10,000 psi.

Stress relieving at 1100° F. (600° C.) removed about 50% of the residual stress. At 1380° F. (750° C.) approximately 70% of the stress was eliminated and at 1470° F. (800° C.) stress relief was technically complete in less than 1 hr.

The mechanical properties of the disks were not improved by the stress-relieving treatments. In fact, the notch-impact toughness was highest in the "as-quenched" specimen.

These results support the often raised question as to whether relief of residual quenching stresses is really necessary. Only in the isolated cases where stress-corrosion cracking would give concern, may the relief of residual tension stresses in the surface be desirable.

Many failures of wrought and welded stainless steels, which have often been ascribed to residual stresses only, in almost all cases may be due to other causes, such as stress-corrosion cracking.

In heat-resistant, cast alloys residual stresses up to and above 20,000 psi. have been measured in mold-cooled castings.[209] Unless these residual stresses are satisfactorily relieved, they may cause serious distortion during subsequent machining operations.

Because of the high hot strength of the heat-resistant castings, the usual stress-relieving treatments are relatively ineffective. The beneficial effects of stress-relieving treatments above 1200° F. (650° C.) probably are further improved by the slight volume change which results from carbide precipitation between 1200° F. and 1900° F. (650° and 1040° C.).[209]

Welding Cold-Worked Stainless Steels

Generally it is undesirable to weld cold-worked stainless steels. This is particularly true when the cold work was introduced to give the steel certain mechanical properties, such as high yield and tensile strengths. Obviously, the welded areas (weld deposit and heat-affected zone) will be softened, and, thus, lose the beneficial effects of the initial work-hardening process. In addition, cold work considerably enhances the diffusion rates and allows carbides to form at much greater rates in sections heated in (or through) the sensitizing range. For this reason, the precipitation band in the heat-affected zone will be wider in cold-worked alloys.

An exception to this may be found in resistance-welding processes. However, proper care has to be taken to insure that the fusion and heat-affected zones do not reach the surface of the stainless steel.[1]

Those grades which have been immunized and then cold worked are less seriously affected. However, during the first welding pass, the areas adjacent to the weld which are heated above 1850° F. (1010° C.) will experience an initial solution of carbides. Slow cooling and subsequent weld beads will again cause intergranular precipitation, which is highly susceptible to intergranular corrosion.[80] Moreover, welding of cold-worked stainless steel reduces the ferrite content in the heat-affected zone.[91]

Severe cold-working of weld deposits caused by forming or bending operations often leads to cracking.[141]

When fabricating or using cold-worked stainless steels, an understanding of the individual characteristics of each stainless grade may allow for more efficient and economical operations. Thus, slight or large cold reductions, or only skin rolling, may give a certain alloy properties which, in a particular structure, may increase its service life tremendously. Other considerations should be made in cold-fabricating operations where the work-hardening characteristics determine the drawability of each alloy. A material that work hardens rapidly may require more drawing operations and heat treatments than an alloy which work hardens more slowly.

Additional factors introduced by structural composition, rate of straining, temperature, stress relieving, and welding may also cause changes in the properties which affect the efficiency of stainless structures and equipment.

EFFECTS OF SUBZERO TEMPERATURES

The austenitic stainless steels are particularly adapted for service at subzero temperatures. This is due to the high degree of austenite stability of most of the common compositions.*

Only in a few alloys may exposure of (metastable) austenitic composition to subzero temperatures cause some of the austenite to transform into ferrite. However, the amount of transformation may be considerably increased by prior cold work, or deformation, during exposure or testing.

Effects on Wrought Stainless Steels

Figure 32 shows results by McAdam, Geil, and Cromwell[74] on annealed austenitic 18-9 (Cr-Ni) alloys containing 0.10% carbon. The curve obtained at room temperature indicates the absence of any significant phase change. The curves at the lower temperatures, however, give clear evidence of a sudden rapid phase change. This is indicated by the reversal in curvature and the rapid increase in slope beyond the point of reversal (*RE*). Therefore, at these temperatures strengthening during plastic extension is caused not only by ordinary work hardening, but also by the transforma-

* The authors bolted together 20 disks having an outside diameter of 6.69 in. (170 mm.) and a concentric hole 2.76 in. (70 mm.) in diameter. The two end disks were 2.36 in. (60 mm.) thick whereas the 18 inner disks were only 0.79 in. (20 mm.) thick.

† Stresses were determined by Heyn-Sachs method.

* A comprehensive survey of the low temperature properties of various common metals and alloys was published recently by Seigle and Brick.[137]

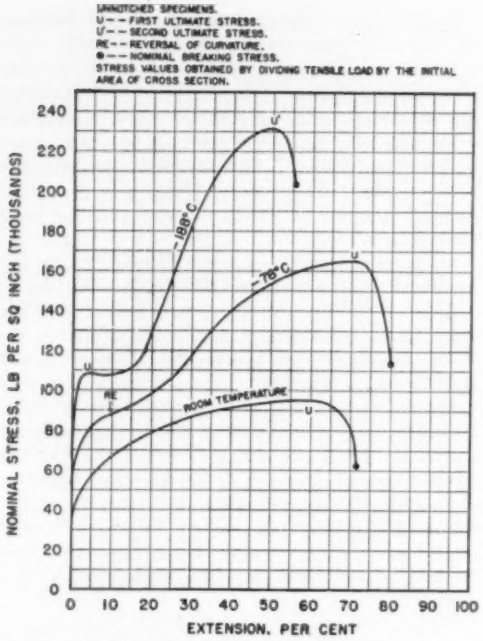

UNNOTCHED SPECIMENS.
U — — FIRST ULTIMATE STRESS.
U' — — SECOND ULTIMATE STRESS.
RE — — REVERSAL OF CURVATURE.
B — — NOMINAL BREAKING STRESS.
STRESS VALUES OBTAINED BY DIVIDING TENSILE LOAD BY THE INITIAL AREA OF CROSS SECTION.
NOMINAL STRESS, LB PER SQ INCH (THOUSANDS)
EXTENSION, PER CENT
-188° C.
-78° C.
ROOM TEMPERATURE
U
U'
RE
B

Fig. 32 Variation of nominal stress with extension, annealed 18–8 (Cr-Ni) stainless steel[74]

tion of austenite to ferrite. The descent at −306° F. (−188° C.) in the nominal stress at *U* is explained by McAdam, Geil, and Cromwell[74] to represent incipient local contraction. In the absence of a phase change the local contraction would have continued and the curve would have descended with increasing slope to a point representing fracture. At *U'* the influence of hardening, caused by the phase change, ceased to be dominant and was indicated by final local contraction.

Although the formation of ferrite does not lower tensile strength and hardness on exposure to subzero temperatures, it is detrimental to impact toughness and ductility. Thus, the fully ferritic stainless steels are seriously embrittled at temperatures near −108° F. (−78° C.).[88] Similarly, the use of compositions, in which a considerable amount of metastable austenite transforms into ferrite, may be highly undesirable. In such cases the more stable austenitic grades should give better service at the extremely low temperatures.

Austenitic stability also has an important bearing on weld deposits. In these the low-temperature brittleness of ferrite has to be considered against the crack sensitivity of the austenite. Careful studies should produce interesting results, particularly from the point of view of applications in arctic atmospheres.

It should be remembered that cold deformation and/or tensile tests, which cause severe internal strains, may considerably promote the formation of ferrite. However, in the absence of such internal straining most of the common grades will remain austenitic down to the lowest testing temperatures. In these alloys, therefore, impact toughness is not severely lowered and the impact specimen does not experience the rapid changes which, because of transformation, are observed in the ductile properties revealed by tensile tests.[155]

Thus, even the common 19–9 (Cr-Ni) grades have remained essentially austenitic at subzero temperatures and, in the absence of internal straining, have shown satisfactory impact toughness.

The formation of an intergranular carbide network in sensitized alloys seems most undesirable. (Sigma may give similar trouble.) Such a carbide network is particularly detrimental to impact toughness as shown by Schmidt[35] in Table 12. The Charpy impact toughness of the sensitized Type 302 alloy containing 0.14% carbon fell from 82.7 ft.-lb. at room temperature to only 10.7 ft.-lb. at −300° F. (−185° C.). The toughness of the sensitized Type 304 alloys with 0.07% carbon was insignificantly lowered. This demonstrates how important it is to avoid the formation of a relatively continuous intergranular carbide film in austenitic alloys used at low temperatures. The carbon content of fully annealed alloys made little difference upon the impact properties.

A large grain size also tends to lower impact toughness at subzero temperatures.[86] However, as was shown earlier, impact toughness is greatly reduced by straining at subzero temperatures (Fig. 29). The reduction is most severe in the metastable 18–8 (Cr-Ni) grades. These considerations hold true in wrought steels as well as in castings and weld deposits.

Table 12—Effect of Subzero Temperatures on Charpy Keyhole Impact Toughness (Average) of Type 302 and Type 304 Stainless Steels[35]

	Composition								*Charpy impact toughness, ft.-lb.*	
Alloy	*C*	*Mn*	*Si*	*P*	*S*	*Cr*	*Ni*	*Testing temperature, ° F.*	*Annealed at 2050° F. and water quenched*	*Sensitized at 1000° F.*
302	0.14	1.08	0.29	0.012	0.012	18.43	8.90	Room	79.7	82.7
								−150	70.9	43.3
								−300	66.5	10.7
304	0.07	0.70	0.77	0.012	0.018	18.69	9.30	Room	75.6	81.1
								−150	82.4	78.7
								−300	79.7	60.0

Effects on Castings and Weld Deposits

Not much has so far been reported on the properties of austenitic stainless castings and weld metal at subzero temperatures. For example, a few data by Juppenlatz[54] on 19–9 (Cr-Ni) castings showed Charpy keyhole impact values to decrease uniformly from about 74 ft.-lb. at 75° F. (24° C.) to 53 ft.-lb. at −425° F. (−254° C.). Although Franks[115] suggested that weld deposits would exhibit high-toughness values at low temperatures, considerable caution seems to be appropriate for the 18–8 (Cr-Ni) types of weld metal.

The notch sensitivity of weld deposits at subzero temperatures is seriously affected by stress-relieving[220, 246] and stabilizing[220] heat treatments. This is evident from Charpy impact data by Krivobok and Thomas[220] which are given in Table 13. Whereas at room temperature the weld metal in the as-welded, stress-relieved [2 hr. at 1200° F. (650° C.)] and annealed [½ hr. at 1950° F. (1065° C.)] states exhibited similar properties, subzero temperatures reduced the notch-impact toughness of specimens in the stress-relieved state more severely than in the as-welded and annealed specimens. The stabilizing heat treatment of 2 hr. at 1550° F. (845° C.) caused also a considerable loss in toughness at subzero temperatures.* Particularly detrimentally affected were the molybdenum-bearing stainless grades (Table 13). The effects of the stress-relieving and stabilizing heat treatments are most harmful on those welds which contain high percentages of ferrite. This is probably related to the formation of the sigma phase.[257]

These results show that weld deposits, which at room temperature already exhibit an impact toughness significantly lower than that of wrought steels, may at subzero temperatures below −150° F. (−100° C.) appear quite notch sensitive. The effects of *stress-relieving* and *stabilizing* heat-treatments appear particularly detrimental on a number of compositions. In these such heat treatments should probably be omitted in order to obtain weld deposits with greatly increased resistance to notch embrittlement at subzero temperatures.

If it is necessary to remove welding stresses of sections which are to be used at subzero temperatures, a heat treatment at 1900° F. (1040° C.) is more advisable

* The toughness of wrought stainless steels is not significantly reduced by stress-relieving treatments between 1300 and 1600° F. (705 and 870° C.).[246]

Table 13—Effects of Heat Treatments on the Charpy Keyhole Impact Properties of Various Weld Metals Tested at Room and Subzero Temperatures[220]

Type of weld deposit	*Heat treatment**	*Ferrite, %*	*Impact toughness, ft.-lb.†*		
			Room temperature	*−105° F. (−75° C.)*	*−320°F. (−196°C.*
301	As-welded	...	36	21	5
	Annealed	...	41	30	24
302	As-welded	...	35	30	26
304	As-welded	...	34	26	20
	Annealed	...	44	40	35
308	As-welded	...	32	23	17
	Annealed	...	36	30	30
310	As-welded	...	36	30	24
	Annealed	...	32	28	19
316	As-welded	0.5	30	26	18
	Stress relieved	...	32	25	13
	Stabilized	...	28	21	13
	Annealed	...	34	29	22
316	As-welded	8.0	31	28	18
	Stress relieved	...	26	17	7
	Stabilized	...	11	7	3
	Annealed	...	37	33	25
317	As-welded	2.0	21	16	11
	Annealed	...	21	16	14
317	As-welded	5.5	11	7	4
	Annealed	...	11	6	3
318	As-welded	None	27	22	15
	Stress relieved	...	26	24	15
	Stabilized	...	21	15	13
	Annealed	...	31	26	20
318	As-welded	0.5	20	16	11
	Stress relieved	...	19	15	9
	Stabilized	None	9	7	5
	Annealed	...	25	20	15
347	As-welded	None	27	22	20
	Stress relieved	...	26	20	13
	Stabilized	...	22	15	14
	Annealed	...	25	25	18
347	As-welded	3.5	30	25	18
	Stress relieved	...	25	15	11
	Stabilized	...	20	16	14
	Annealed	...	26	25	24

* Heat treatments were as follows:
As-welded
Stress relieved 2 hr. at 1200° F. (650° C.)—AC.
Stabilized 2 hr. at 1550° F. (845° C.)—AC.
Annealed ½ hr. at 1950° F. (1065° C.)—WQ.

† Average of 2 to 6 tests.

than the stress-relieving treatment at intermediate temperatures.

Very little is known about the effects of the individual elements. However, some preliminary data indicate that the molybdenum-bearing 18–8 (Cr-Ni) grades experience the most severe loss in toughness by stress-relieving and stabilizing heat treatments.[219, 220]

Holler and Schnedler[108] conducted detailed studies on the mechanical properties at low temperatures of welds made on a silicon-bearing 25–20 (Cr–Ni) steel. The authors, in comparing this alloy with a ferritic stainless steel and with carbon steels, found the austenitic stainless steel superior in a number of properties, particularly toughness and elongation. In their tests, 0.254 in. thick plates of the four steels were welded as indicated in Table 14. The pertinent test results on the parent metal and welded sections are shown in Figs. 33 to 36.

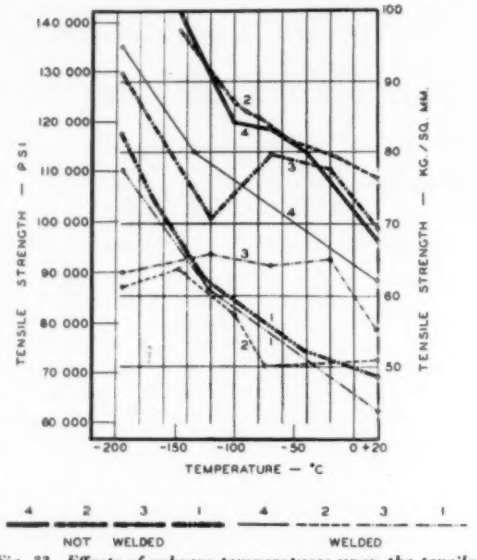


Fig. 33 Effects of subzero temperatures upon the tensile strength of several types of steels and weld deposits[108]

In all four steels the properties of the weld (cast structure) were below those of the wrought parent metal. The impact properties of the silicon-bearing austenitic steel were the only exception. They remained high down to −58° F. (−50° C.) as shown in Fig. 35. In the tension tests the austenitic alloys failed in the weld, whereas in the chromium stainless steels failure occurred either in the weld or in the heat-affected zone.

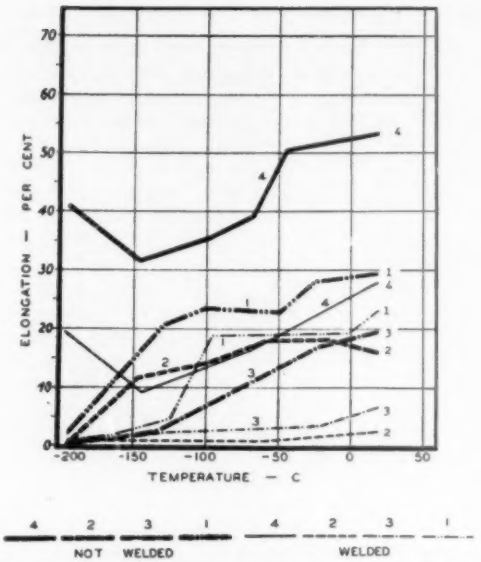


Fig. 34 Effects of subzero temperatures upon the elongation of several types of steels and weld deposits[108]

Of greatest interest is the fact that, of the alloys studied by Holler and Schnedler, the mechanical properties of the ferritic stainless steel are affected far more detrimentally than any of the other three types of steels tested.

One of the major disadvantages of all of the ferritic steels is that they experience a transition from ductile to brittle behavior (high notch sensitivity). The temperature at which this transition occurs depends upon a number of factors such as composition, type of notch, etc., and may lie above or below ordinary temperatures. As the austenitic stainless steels are not subject to this transition, their use may be essential in structures and equipment exposed to low temperatures under notch-sensitive conditions. During the recent war a considerable amount of German war equipment made from or welded with ferritic stainless steels failed in Russia during the severe winter of 1941–42 because, at the existing subzero temperatures, these steels had become extremely notch sensitive. Such failures would not have occurred if austenitic stainless steels and/or welding electrodes had been used.

Table 14—Analyses and Welding Techniques of Series of Steels Tested at Low Temperatures[108]

Steel No.	*C*	*Mn*	*Si*	*Mo*	*Cr*	*Ni*	*Welding technique*	*Electrode*
1	0.13	...	...	...	...	...	Gas	GV3
2	0.42	...	...	...	...	...	Gas	GV3
3	0.40	...	...	1.8	17.68	...	Electric arc	Griesheim MAS
4	0.08	1.15	1.40	...	24.66	19.25	Electric arc	Griesheim Therma

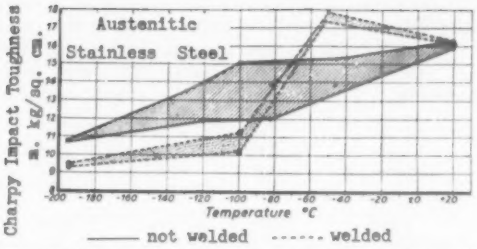


Fig. 35 Effects of subzero temperatures upon the notch impact toughness of austenitic stainless steel No. 4.[170]

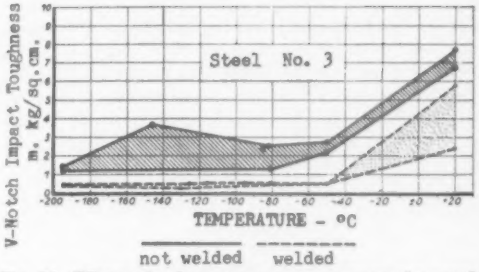


Fig. 36 Effects of subzero temperatures upon the notch impact toughness of chromium stainless steel No. 3.[10] *(45° V-notch, 2 mm. deep, specimen 10 x 7 x 55 mm.)*

EFFECTS OF ELEVATED TEMPERATURES

For service at high temperatures the use of fully austenitic compositions is generally desirable if maximum hot strength is wanted. However, where maximum protection against unexpected or unpredictable stresses is required, the partially ferritic grades *may* have an advantage. The desire to produce partially ferritic 18–8 (Cr-Ni) weld deposits, which are thereby less sensitive to hot cracking, is an example of the benefits of the presence of small quantities of ferrite.

Strength vs. Ductility

As Avery, Cook, and Fellows[98] and Evans[165] pointed out, the relative importance of strength and ductility at elevated temperatures is not always understood. Although ductility may seem desirable to relieve overloads by plastic flow, sufficient strength should obviate the need for stress relief by deformation. Moreover, the relative importance of these factors may vary with the service requirements to which the alloys are subjected. Some service conditions contain unknown factors that prevent precise design calculations. It is a common practice in these situations for engineers to depend on hot ductility for stress redistribution rather than on maximum hot strength, since unexpected loads before stress redistribution occurs may be sufficient to fracture a strong, but relatively brittle, alloy.[205] That is why both strong (austenitic) and ductile (partially ferritic) types have been incorporated in the ASTM Specification B 190 – 45 T.

Creep Resistance

Structural composition represents the most important factor affecting creep resistance.[10] Thus, alloying elements which go into solution in the austenitic matrix play a relatively small role. On the other hand, those elements, which precipitate compound particles (carbides, etc.) or tend to support ferrite or sigma formation, are highly important. However, although a fine precipitate is highly beneficial, agglomeration of the particles generally reduces creep resistance to values below those which would have been obtained if no precipitate were present in the alloy.

Creep data published for various wrought stainless steels by Evans[165] are repeated in Table 15.

Investigating the effects of cold work on the creep re-

Table 15—Creep Data of Various Wrought Austenitic Stainless Steels Exposed at Elevated Temperatures[165]

A.I.S.I. type	*800° F. (425° C.)*	*900° F. (480° C.)*	*1000° F. (540° C.)*	*1100° F. (595° C.)*	*1200° F. (650° C.)*	*1300° F. (705° C.)*	*1400° F. (760° C.)*	*1500° F. (815° C.)*	*1600° F. (870° C.)*
			Stress for Secondary Creep Rate of 0.10% in 1000 Hr.						
302	...	...	21,000	14,000	10,000	8500	4000	1000	...
304	37,500	28,000	19,500	14,750	7,500	4500	2750	2000	...
A*	...	...	25,000	11,000	6,000	4000	2500	1200	...
347	...	...	22,500	19,000	10,500	3800	2500	...	...
316	...	...	24,000	19,000	12,800	8000	5300	3300	...
309	...	...	17,000	13,000	8,800	4500	2000	1200	...
310	...	...	19,000	15,500	10,000	4500	2250	1000	...
B†	...	...	24,000	16,000	9,500	5500	3500	2000	1500
			Stress for Secondary Creep Rate of 0.01% in 1000 Hr.						
302	...	...	9,500	7,800	6,500	4300	2300	800	...
304	24,500	17,000	11,250	7,250	4,000	2250	1500	1250	...
A*	...	...	20,000	9,500	5,500	3500	2000	800	...
347	...	...	...	12,000	8,000	2000	...	...	...
316	...	...	15,000	12,000	7,000	4000	2700	1500	...
309	...	...	...	10,000	...	...	...	...	...
310	...	...	11,000	8,750	6,250	5000	4000	...	...
B†	...	...	20,500	14,000	8,000	4000	...	...	...

* Stock with 0.15% carbon, 8.5% chromium, and 20% nickel.
† Stock with 0.20% carbon, 15% chromium, and 35% nickel.

Table 16—Stress-to-Rupture Values of Wrought Austenitic Stainless Steels between 1000 and 1600° F.[165]

Type	1000° F. (540° C.)	1100° F. (595° C.)	1200° F. (650° C.)	1300° F. (705° C.)	1400° F. (760° C.)	1500° F. (815° C.)	1600° F. (870° C.)
			Stress-to-Rupture in 1000 Hr.				
304	...	...	11,500	9,250	6,500	3,500	2,750
347	...	27,500	20,000	12,500	...	...	...
316	...	...	25,000	18,000	11,000	7,000	4,000
310	30,750	20,500	13,250	7,750	4,500	3,000	2,250
			Stress-to-Rupture in 100,000 Hr. (Extrapolated)				
304	...	...	8,500	4,000	3,000	1,500	1,300
347	...	16,500	11,000	4,500	...	...	...
316	...	...	12,500	9,000	4,200	1,500	800
310	15,500	10,000	5,500	3,000	2,500	1,000	750

sistance of several wrought 18–8 (Cr-Ni) type alloys, Zschokke[189] found that above 1380° F. (750° C.) the creep strength is reduced. Between 750 and 1380° F. (400 and 750° C.) an increasing amount of cold work first raises the creep strength to a maximum. Cold reductions in excess of a certain limit would reduce creep strength considerably. Below 750° F. (400° C.) cold work improves creep strength.

Stress-to-Rupture Properties

Stress-rupture data provide the engineer with the greatest amount of useful information.[165] Data for wrought austenitic stainless steels, taken from a detailed discussion by Evans,[165] are given in Table 16.

Heat treatments and grain size also have a considerable influence on the stress-to-rupture values. Thus, the stress-to-rupture values increase with grain size. For example, a 25–20 (Cr-Ni) stainless steel in a coarse-grained condition (ASTM size 2 to 4), exhibited[252] a stress-to-rupture value at 1400° F. (760° C.) of 2800 psi. in 100,000 hr. In the fine-grained condition (ASTM size 9) the stress-to-rupture value amounted to 450 psi. This difference in strength is particularly startling when interpreted in terms of potential life. If a stress of 2800 psi. were applied to the fine-grained material, which had a 100,000 hr. rupture strength of 450 psi., failure would occur in about 1000 hr. instead of 100,000 hr.

The effects of heat treatments on weld deposits are illustrated in Table 17.[190] The stress-to-rupture tests were performed at 1200° F. (650° C.).

In the partially ferritic, columbium-bearing 19–9 (Cr-Ni) steel a heat treatment of 100 hr. at 1350 and 1450° F. (730 and 790° C.) results in a considerable improvement of the stress-to-rupture strength over values obtained on the "as-welded" specimen. The strengthening is probably due to the age-hardening effects of the columbium carbide and the transformation of some ferrite into very finely distributed sigma particles. Periods in excess of 100 hr. (and/or internal straining) would lower the stress-to-rupture strength due to coagulation of the sigma particles.

In the fully austenitic 25–20 (Cr-Ni) steel the reduction in stress-to-rupture strength caused by prior heat treatments at 1350 and 1450° F. (730 and 790° C.) may well be due to the formation of an intergranular sigma precipitate. In addition, intergranular carbide precipitation may also be a factor.[190]

Effects of Columbium

The fact that the columbium-bearing 18–8 (Cr-Ni) (Type 347) steels show excellent high-temperature strength characteristics up to about 1200° F. (650° C.) is noticeable. This, as Binder[191] pointed out, may be attributed to a dispersion-hardening phenomenon in which the sigma phase is precipitated in a critical particle size at the grain boundaries. Below 1200° F. (650° C.) the formation of sigma is sufficiently retarded to prevent growth and coagulation of the finely distributed particles. Above 1200° F. (650° C.) the growth and coagulation of the particles which occurs decreases the beneficial effects of the fine precipitate and severely lowers the high-temperature strength of the steel (see Table 15). The coagulation and growth of the sigma particles are caused by the long holding periods and the internal straining of the stress-to-rupture test. The

Table 17—Effects of Prior Heat Treatments on the Stress-to-Rupture Strength at 1200° F. (650° C.) of a Partially Ferritic, Columbium-Bearing 19–9 (Cr-Ni) and a Fully Austenitic 25–20 (Cr-Ni) Weld Metal[190]

Prior heat treatment	Stress, psi.	Fracture time	Elongation, %*
	19–9–Cb (Cr-Ni-Cb)—Partially Ferritic		
As-welded	28,000	693	5.0
100 hr.—1250° F.	28,000	783	6.0
100 hr.—1350° F.	28,000	912	5.0
100 hr.—1450° F.	28,000	884.5	6.0
100 hr.—1550° F.	28,000	619	7.0
100 hr.—1650° F.	28,000	231.5	7.0
1 hr.—1750° F.—AC	28,000	787	15.0
5 hr.—1600° F.—AC	28,000	477	4.8
	25–20 (Cr-Ni)—Fully Austenitic		
As-welded	20,000	237	4.0
100 hr.—1250° F.	20,000	341	5.0
100 hr.—1350° F.	20,000	171.5	9.0
100 hr.—1450° F.	20,000	123.0	0
100 hr.—1550° F.	20,000	356	10
100 hr.—1650° F.	20,000	334.5	15
1 hr.—1750° F.—AC	20,000	425.5	0
5 hr.—1600° F.—AC	20,000	381.5	0

* The elongation of these alloys is difficult to measure accurately due to type of fracture.

reason why the 100 hr. preheat treatment at 1450° F. (790° C.) (Table 17) seems most beneficial is that the 100 hr. and the absence of straining did not cause an excessive growth of the sigma particles.

Effects of Ferrite

In hot-rolling or forging operations 18–8 (Cr-Ni) type alloys having a mixed structure of ferrite and austenite tend to crack at the edges. This cracking tendency might well be caused by differences in the plasticity of the soft ferrite and the tough austenite at rolling and forging temperatures.[64, 79, 82, 100] The presence of ferrite also reduces the load-carrying properties of the alloy. Because of these reasons, the nickel content is usually adjusted to prevent the formation of ferrite.

However, partially ferritic materials have a definite field of usefulness because, in appropriate sections, they can replace lighter castings of high strength to provide a factor of safety for installations where unusually excessive stresses cannot be avoided by design.[93] For example, oil-refinery engineers generally depend more on ductility than they do on strength for their safety factor.[200]

Considerable differences of opinion exist on the effects of ferrite on the creep strength and the stress-to-rupture life of austenitic stainless steels and weld metal. The differences may often be resolved by the fact that in many partially ferritic compositions some (or all) of the ferrite tends to transform into sigma during the long testing periods used in the evaluation of creep and stress-to-rupture properties. Since a small quantity of highly dispersed sigma particles is generally believed to be beneficial to these properties, sigma precipitation, rather than ferrite, may have been responsible for these higher rupture-strength values. On the other hand, coagulation of the sigma particles is again detrimental. In addition slight differences seem to exist in the effect of ferrite in wrought steels, castings, and weld deposits.

Thus, the formation of a small, highly dispersed quantity of sigma may explain Hochmann's[101] observation that a small, well dispersed amount of ferrite in the austenitic matrix of wrought grades seemed beneficial to the creep resistance.[101] Large quantities of ferrite, however, seem undesirable. Thus, Avery, Cook, and Fellows[93] foupd that "the amount of ferrite developed with or without stress at elevated temperatures is an inverse function of the creep strength."

Monypenny[106] also observed that a steel containing some ferrite is very susceptible to serious embrittlement when held for long periods in the intermediate-temperature range. He reported that a turbine blade alloy made of titanium-stabilized 18–8 (Cr-Ni) steel, which also contained 1.5% aluminum, exhibited an Izod impact toughness of 50 ft.-lb. in the softened condition. Heating for 12 hr. at 840° F. (450° C.) reduced the toughness to 10–12 ft.-lb. which decreased still further with more prolonged heating. Because of the rapid rates of embrittlement at 840° F. (450° C.), Monypenny cautioned against the use even at lower temperatures of wrought steels containing duplex structures.

Transformation to and growth of highly alloyed ferrite in wrought 18–8 (Cr-Ni) cracking-still tubes were blamed for causing their failure after service exposures up to 97,520 hr. at 1200 to 1250° F. (650 to 675° C.). An accompanying stress was a primary prerequisite.[96, 97]

In weld deposits as is true in wrought steels and castings the rupture strength is generally reduced by the presence of ferrite. However, the ferrite phase, when it is present, is finely dispersed. As such the sigma particles, which form in short periods of exposure at 1200° F. (650° C.), are very small and in this state are generally believed to increase the rupture strength.

Typical stress-to-rupture values at 1200° F. (650° C.) of several austenitic weld metals are listed in Table 18.[199] It is likely that the lower stress-to-rupture value of 16,000 psi. of the 18–8–Cb (Cr-Ni-Cb) alloy represented an alloy in which ferrite was present. The higher stress-to-rupture value of 21,000 psi. is probably due to the fact that all of the ferrite transformed which resulted in very small and highly dispersed sigma particles. Many of the 18–8–Cb or 18–8–Mo specimens which contain some ferrite in the as-welded condition will show only austenite and sigma particles after the stress-to-rupture test.

The results listed in Table 18 indicate that 18–8–Cb (Cr-Ni-Cb) weld metals seem to be the most satisfactory from the standpoint of high-temperature strength—in spite of the fact that the specimen initially contained 10% ferrite. The presence of 10% ferrite would be highly undesirable in a wrought alloy of similar composition.[199] It might well be that the differences between weld metal and wrought alloys are due to the fact that in weld deposits the initial ferrite patches are small and finely distributed which at temperatures near 1200° F. (650° C.) may, in a few partially ferritic grades, result in relatively fine and well dispersed sigma particles.

Table 18—Stress-to-Rupture Values of Austenitic Weld Deposits Tested at 1200° F. (650° C.)[199]

Alloy	*Structure*	*Composition*							*Extrapolated stress-to-rupture in 10,000 hr.*
		C	*Mn*	*Si*	*Mo*	*Cr*	*Ni*	*Cb*	
25–20	Austenitic	0.22	2.10	0.54	...	25.06	21.09	...	5400 psi.
18–8 Cb	Austenite + 10% ferrite	0.09	1.65	0.56	...	19.70	9.84	1.05	16,000 to 21,000 psi.
		0.08	1.52	0.45	...	19.55	10.15	1.08	
25–20 Cb	Austenitic	0.13	1.84	0.65	...	25.30	20.25	1.20	13,000 to 16,000 psi.
18–8 Mo	Austenite + approximately 4% ferrite	0.09	2.24	0.63	2.16	18.84	13.07	...	14,000 psi.

Precipitation of Compound Particles

It was already mentioned that sigma particles in a very small and highly dispersed state are believed to be beneficial on the short-time tensile properties. Thus, Guarnieri, Miller, and Vawter[135] reported that the creep strength of 25–20 (Cr-Ni) steels containing 2% silicon is increased for relatively short-life applications by small quantities of sigma. The short-life applications involve deformation of the order of 1% per hour for temperatures up to approximately 1400° F. (760° C.). Where slow strain rates are involved, as in long-service-life applications, the sigma phase generally reduces creep resistance. Since in stainless steels, which are susceptible to sigma formation, a fine grain size enhances sigma formation considerably more than a coarse grain size would, coarse-grain steels are preferred. Thus, a heat treatment above 1900 to 2100° F. (1040 to 1150° C.) of sufficient length to cause grain coarsening may be beneficial because it greatly increases the long-service-life of the steel at temperatures at which sigma may form. The advantages of a coarse grain size on creep and rupture strengths are particularly evident in wrought 25–12 and 25–20 (Cr-Ni) stainless steels. Because an excessive amount of sigma is highly detrimental, compositions in which considerable quantities of sigma form are generally avoided for most applications at elevated temperatures.

The precipitation of other types of particles may be more desirable. Their effects on the mechanical properties of the stainless steels depend on several factors. Most important are amount, size, and distribution of the particles. Grain size and microstructure of the stainless matrix should also be considered.

Effects of Carbon Content

Precipitation of carbides generally improves the short-time tensile properties, creep resistance, and hot ductility at elevated temperatures. However, an excessive amount of carbides may again be detrimental.

Between 0.10 and 0.20% carbon seems to act most favorably in wrought stainless steels of intermediate chromium and nickel content. For example, data by Hochmann[101] on austenitic 18–8 (Cr-Ni) alloys exposed between 1020 and 1470° F. (550 and 800° C.) showed that, depending upon load and temperature, minimum creep rates were obtained for a carbon content from approximately 0.14 to 0.20%. Similarly, in fully austenitic 14–14–2 (Cr-Ni-W) compositions, a carbon content between 0.1 and 0.2% gave best results when high-plastic properties and high-tensile strength were desired at temperatures near 1500° F. (815° C.).[102]

In the more highly alloyed 25–20 or 15–35 (Cr-Ni) grades a higher-carbon content (above 0.20%) may seem desirable. This is apparent from results by Avery[208] on 16–35 (Cr-Ni) heat-resistant castings which showed their most favorable creep properties at a carbon level of about 0.45%, Fig. 37. Since hot ductility also improved with carbon content (Fig. 12), these results indicate the advantages of the higher carbon, heat-resistant alloys. The effects of carbon content on the stress-to-rupture and creep properties of 0.10% carbon 24–19 (Cr-Ni) and 0.30% carbon 26–20 (Cr-Ni) alloys are illustrated in Fig. 38. For comparison the characteristics of ferritic, chromium stainless steels are also shown. (Of course, in many corrosive applications the higher carbon content would generally be undesirable because of possible intergranular corrosion which would be due to intergranular carbide precipitation.)

Creep resistance is highest as long as the carbides are well dispersed. The beneficial effects of carbide dispersion may be readily associated with the prior solution heat treatment. For a wrought 25–20 (Cr-Ni) steel this is illustrated in Fig. 39.[206] The higher the solution temperatures, that is, the greater the amount of carbides that are allowed to dissolve in the austenite matrix (see Fig. 11), the denser will be the dispersion of the new carbide particles which form when the steel is exposed to intermediate temperatures. Hot ductility, however, is reduced as higher preheat treatments are employed.

Similar results were pointed out by Austin and Samans[73] in studies on an alloy containing 0.07% C, 18.73% Cr, 9.46% Ni, and 0.40% Mn. The authors found that heating a quenched alloy (carbon in solution) between 1110 and 1290° F. (600 and 700° C.) resulted in a fine precipitate (apparently carbides) appearing principally in the grain boundaries and in the ends and sides of twin bands. In this temperature range a larger grain size increased the creep resistance of the alloy. The beneficial effects were probably caused by the more uniform (submicroscopic) distribution of carbides.

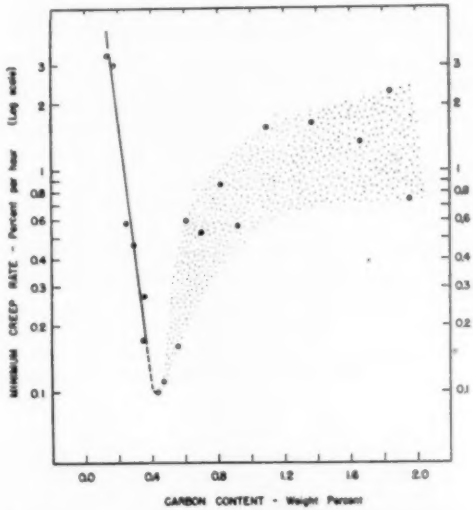


Fig. 37 The effect of carbon on the creep resistance of cast 16–35 (Cr-Ni) heat resistant alloys from stress-strain-rupture tests at 1400° F. (760° C.) and 20,000 psi.[208]

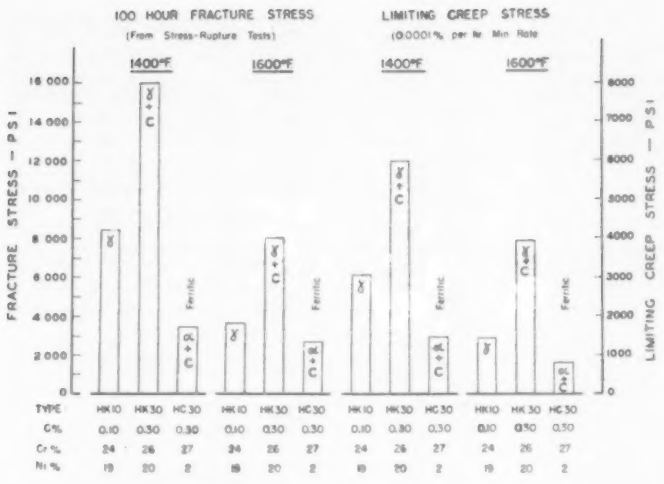

100 HOUR FRACTURE STRESS
(From Stress-Rupture Tests)
LIMITING CREEP STRESS
(0.0001% per hr Min. Rate
1400°F
1600°F
1400°F
1600°F
FRACTURE STRESS — PSI
LIMITING CREEP STRESS — PSI
Ferrite
TYPE HK10 HK30 HC30 HK10 HK30 HC30 HK10 HK30 HC30 HK10 HK30 HC30
C% 0.10 0.30 0.30 0.10 0.30 0.30 0.10 0.30 0.30 0.10 0.30 0.30
Cr% 24 26 27 24 26 27 24 26 27 24 26 27
Ni% 19 20 2 19 20 2 19 20 2 19 20 2

***Fig. 38** Elevated temperature properties of ferritic and austenitic stainless castings.[70] (α = ferrite, γ = austenite, c = carbide)*

Austin and Samans[73] found that the strengthening effect persisted for at least 2000 hr. However, higher test temperatures or longer periods decreased the resistance to deformation. Quite likely this was caused by agglomeration of the carbide particles.*

Stainless steels which are shaped by forging are detrimentally affected by the presence of chromium carbides. The hardening effects produced by the carbides in alloys containing over 0.15% C generally reduce their forgeability considerably.[75] Another disadvantage of chromium-carbide hardening is that the loss in free chromium will lower the oxidation resistance of the alloy.[75]

* Such agglomeration which is caused by excessive temperatures or exposure periods and which reduces the beneficial effects of precipitation hardening is usually called overaging.

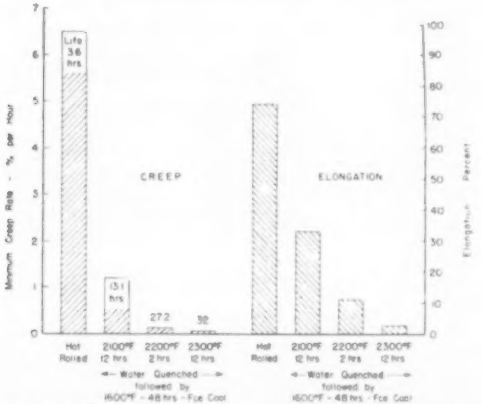


***Fig. 39** Effect of solution temperature on stress-rupture properties of wrought 25–20 (Cr-Ni) heat resistant alloy. Stress-strain-rupture properties 1600° F. (870° C.) and 7000 psi.[216]*

Improved results may be obtained by the addition of minor alloying elements. Thus, beryllium is one of the most effective age-hardening elements. Unfortunately, the age-hardening temperatures are quite low, so that overaging may occur when the alloy is used above 1100° F. (535° C.).[75]

For service between 1100 and 1400° F. (535 and 760° C.) age-hardening effects are generally produced in stainless steels by the addition of columbium,[2] titanium,[2] or copper. At higher temperatures molybdenum additions are commonly made.[75]

Carbon is kept generally at a minimum in these alloys, because the formation of columbium or titanium carbides would reduce the age-hardening effects of these elements.[75]

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Correction:

In the review "Alloying Elements in Chromium-Nickel Stainless Steels," [THE WELDING JOURNAL, **29**, Res. Supplement, 361-s to 404-s (1950)] on page 367-s, the second paragraph, last sentence should read:

"If such weldments are heated to stabilizing temperatures above 1400° F. (760° C.), columbium and carbon combine to form stable carbides and intergranular attack cannot be observed by the usual tests."

Suggested Heat Treatment and Forming Data for Boiler and Pressure Vessel Steels

Prepared by the Materials Division, Pressure Vessel Research Committee of the Welding Research Council from an original tabulation by W. P. Gerhart, Bethlehem Steel Co.

ASTM SPEC.		CHEMICAL REQUIREMENTS, PER CENT (1)								TENSILE (2) STRENGTH REQUIREMENT P.S.I.	THICKNESS RANGE (3) INCHES	ANNEALING TREATMENT (4)		NORMALIZING TEMP °F (4)	HOT FORMING TEMP RANGE °F (5)
NO.	GRADE	CARBON	MANGANESE	SILICON	NICKEL	CHROMIUM	MOLYBDENUM	COPPER	VANADIUM			TEMP °F	COOLING RATE		
A 30	A	0.25 MAX	0.30-0.80					0.25 MAX		55/65,000	1/4 - 3/4	1600	FURNACE COOL	1700	1750 - 1550
		0.30 MAX	" "					"		" "	3/4 - 2	"	TO 1300°F	"	" "
	B	0.25 MAX	" "					"		48/58,000	1/4 - 3/4	"	@ 30°/HR;	"	" "
		0.30 MAX	" "					"		" "	3/4 - 2	"	AIR COOL	"	" "
A 201	A	0.20 MAX	0.80 MAX	0.15-0.30						55/85,000	1/4 - 1	1800	FURNACE COOL	1700	1750 - 1550
		0.24 MAX	"	" "						" "	1 - 2	"	TO 1300°F	"	" "
		0.27 MAX	"	" "						" "	2 - 4	"	@ 30°/HR;	"	" "
	B	0.24 MAX	"	" "						60/70,000	1/4 - 1	"	AIR COOL	"	" "
		0.27 MAX	"	" "						" "	1 - 2	"		"	" "
		0.30 MAX	"	" "						" "	2 - 4	"		"	" "
A 202	A	0.17 MAX	1.05 - 1.40	0.60-0.90		0.30-0.60				75/90,000	1/4 - 1	1550	FURNACE COOL	1600	1700 - 1500
		"	" "	" "		" "				" "	1 - 2	"	TO 1100°F	"	" "
	B	0.25 MAX	" "	" "		" "				65/100,000	1/4 - 1	"	@ 20°/HR;	"	" "
		"	" "	" "		" "				" "	1 - 2	"	AIR COOL	"	" "
A 203	A	0.17 MAX	0.80 MAX	0.15-0.30	2.00-2.75					65/77,000	1/4 - 1	1475		1600	1650 - 1450
		"	"	" "	" "					" "	1 - 2	"		"	" "
		0.20 MAX	0.90 MAX	" "	" "					" "	2 - 4	"		"	" "
	B	"	0.80 MAX	" "	" "					70/82,000	1/4 - 1	"		"	" "
		"	"	" "	" "					" "	1 - 2	"		"	" "
		0.23 MAX	0.90 MAX	" "	" "					" "	2 - 4	"		"	" "
	C	0.25 MAX	0.80 MAX	" "	" "					75/87,000	1/4 - 1	"	FURNACE COOL	"	" "
		"	"	" "	" "					" "	1 - 2	"	TO 900°F	"	" "
		0.27 MAX	0.90 MAX	" "	" "					" "	2 - 4	"	@ 20°/HR;	"	" "
	D	0.17 MAX	0.80 MAX	" "	3.25-3.75					65/77,000	1/4 - 1	1425	AIR COOL	"	" "
		"	"	" "	" "					" "	1 - 2	"		"	" "
		0.20 MAX	0.90 MAX	" "	" "					" "	2 - 4	"		"	" "
	E	"	0.80 MAX	" "	" "					70/82,000	1/4 - 1	"		"	" "
		"	"	" "	" "					" "	1 - 2	"		"	" "
		0.23 MAX	0.90 MAX	" "	" "					" "	2 - 4	"		"	" "
A 204	A	0.18 MAX	0.90 MAX	0.15-0.30			0.40-0.60			65/77,000	1/4 - 1	1600		1650	1700 - 1550
		0.21 MAX	"	" "			" "			" "	1 - 2	"		"	" "
		0.23 MAX	"	" "			" "			" "	2 - 4	"		"	" "
	B	0.20 MAX	"	" "			" "			70/82,000	1/4 - 1	"	FURNACE COOL	"	" "
		0.23 MAX	"	" "			" "			" "	1 - 2	"	TO 1200°F	"	" "
		0.25 MAX	"	" "			" "			" "	2 - 4	"	@ 20°/HR;	"	" "
	C	0.23 MAX	"	" "			" "			75/87,000	1/4 - 1	"	AIR COOL	"	" "
		0.26 MAX	"	" "			" "			" "	1 - 2	"		"	" "
		0.28 MAX	"	" "			" "			" "	2 - 4	"		"	" "
A 212	A	0.28 MAX	0.90 MAX	0.15-0.30						65/77,000	1/4 - 1	1550		1700	1700 - 1500
		0.31 MAX	"	" "						" "	1 - 2	"	FURNACE COOL	"	" "
		0.33 MAX	"	" "						" "	2 - 4	"	TO 1200°F	"	" "
	B	0.31 MAX	"	" "						70/82,000	1/4 - 1	"	@ 20°/HR;	"	" "
		0.33 MAX	"	" "						" "	1 - 2	"	AIR COOL	"	" "
		0.35 MAX	"	" "						" "	2 - 4	"		"	" "
A 225	A	0.18 MAX	1.45 MAX	0.15-0.30					0.08-0.14	70/82,000	7/8 - 1	1800		1700	1750 - 1550
		"	"	" "					" "	" "	1 - 2	"		"	" "
		"	"	" "					" "	" "	2 - 4	"	FURNACE COOL	"	" "
	B	0.20 MAX	"	" "					" "	75/87,000	1/4 - 1	"	TO 1200°F	"	" "
		"	"	" "					" "	" "	1 - 2	"	@ 20°/HR;	"	" "
		"	"	" "					" "	" "	2 - 4	"	AIR COOL	"	" "
A 285	A	0.15 MAX	0.80 MAX					*0.35 MAX		45/55,000	TO 3/4	1800		1700	1750 - 1550
		0.17 MAX	"					"		" "	3/4 - 2	"		"	" "
	B	0.20 MAX	"					"		50/60,000	TO 3/4	"	FURNACE COOL	"	" "
		0.22 MAX	"					"		" "	3/4 - 2	"	TO 1300°F	"	" "
	C	0.25 MAX	"					"		55/65,000	TO 3/4	"	@ 30°/HR;	"	" "
		0.30 MAX	"					"		" "	3/4 - 2	"	AIR COOL	"	" "
A 299		0.28 MAX	0.90-1.40	0.15-0.30						75/90,000	TO 1	1550		1600	1700 - 1500
		0.31 MAX	" "	" "						" "	1 - 2	"	FURNACE COOL TO 1200°F @ 20°/HR; AIR COOL	"	" "
A 301		0.21 MAX	0.80 MAX	0.15-0.30		0.50-0.70	0.40-0.60			65/82,000	TO 1	1800		1700	1700 - 1550
		"	"	" "		" "	" "			" "	1 - 2	"	FURNACE COOL TO 1200°F @ 20°/HR; AIR COOL	"	" "
		"	"	" "		" "	" "			" "	2 - 4	"		"	" "
A 302	A	0.20 MAX	0.90-1.30	0.15-0.30			0.40-0.60			75/95,000	TO 1	1550		1600	1700 - 1550
		0.23 MAX	" "	" "			" "			" "	1 - 2	"		"	" "
		0.25 MAX	" "	" "			" "			" "	2 - 4	"	FURNACE COOL TO 1200°F @ 20°/HR; AIR COOL	"	" "
	B	0.20 MAX	1.10 - 1.50	" "			" "			80/100,000	TO 1	"		"	" "
		0.23 MAX	" "	" "			" "			" "	1 - 2	"		"	" "
		0.25 MAX	" "	" "			" "			" "	2 - 4	"		"	" "

Notes

* Only when specified.

(1) Requirements for phosphorus and sulphur, which differ between flange and firebox grades, not included in this table. See individual A.S.T.M. specifications.

(2) Requirements for yield point and elongation not included in this table. See individual A.S.T.M. specifications.

(3) Thicknesses in excess of 4 in. not covered. See individual A.S.T.M. specifications.

(4) Holding times at temperature for annealing and normalizing should be not less than 1 hr. per inch of thickness.

(5) Temperature ranges selected for hot forming are expected to give minimum of grain growth at the maximum of the range and a minimum of distortion at the bottom of the range. Final adjustment to size may be done below the minimum of the range provided the metal shows a red heat and the distortion is not excessive. *Caution:* Refrain from any forming after the metal has reached a black heat—1000 to 400° F.

A.S.T.M. Specifications and A.S.M.E. Rules permit the following: If the required heat treatment is to be obtained in conjunction with the hot-forming operation, the temperature to which the plates are heated for hot forming shall be equivalent to and shall not significantly exceed the normalizing temperature.

Remarks

Cold Forming: There are no prescribed limits to cold forming operations since composition, heat treatment and amount of hot reduction of the steel, as well as the geometry of the part and its orientation with respect to rolling direction of the plate, are all involved. For shells, cold forming is not generally advisable when the diameter of the shell is less than 5 times the bend-diameter of the bend-test specimen prescribed in the material specification. Plates in excess of 2 in. in thickness should first be normalized when cold forming is necessary. Annealing is also satisfactory, but results in lower plate strength.

Stress-Relieving: Although not mandatory, stress-relieving after hot or cold forming is often desirable, in which case technique may be similar to that specified in Paragraph UW-40, Rules for Construction of Unfired Pressure Vessels, Section VIII, A.S.M.E. Boiler Code (1950 Edition). Temperature should be a minimum of 1100° F. for one hour per inch of metal thickness. It is sometimes convenient to delay stress-relieving of hot formed vessels until after welding.

The Flow and Fracture of Metals

A selected bibliography of comprehensive treatises prepared by Materials Division, The Pressure Vessel Research Committee, Welding Research Council

THE references given below have been selected by the Materials Division, Pressure Vessel Research Committee of the Welding Research Council from well over three thousand technical papers dealing with fundamental concepts of the flow and fracture of metals under various types and combinations of stress and throughout the temperature range to which metals are exposed in service.

These treatises are recommended to those investigators who desire understanding of the fundamentals but do not have the time nor perhaps the inclination to examine more than a small portion of the extensive literature concerned with the various phases of this complex subject. The papers selected for the list are considered to be both comprehensive and authoritative; collectively they are representative of the prevailing state of knowledge and theory concerning the complexities involved in the flow and fracture of metals.

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Weldcracking and Blue-Brittleness

The following is published for the purpose of inviting discussion

by L. W. C. Gaymans

WELDCRACKING has been the subject of many papers and reports, but most of them are devoted to underbead cracking or cracking in the heat-affected zone, only a limited number of publications exists about the cracking tendency of the weld itself.

When limiting ourselves to welds made on mild steel with E6012 or E6013 type electrodes, it often happens that if cracking of the weld is experienced this occurs quite unexpectedly.

It is stated that these sporadic occurrences of unforseen cracking may be due to various fluctuations in

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parent metals, electrodes and welding conditions or perhaps to unhappy conjunctions of such fluctuations.[1] Notwithstanding the fact that electrode manufacturers make every endeavor to prevent cracking troubles with their electrodes and much is known about some harmful conditions and parent metal compositions, these sudden occurrences of cracking have not been eliminated.

When investigating such cracking troubles it is in some cases possible to establish the probable cause but in many cases it remains beyond our present knowledge to indicate the reason for its occurrence. The type of cracks we have under consideration are the so-called hot cracks. Such cracks generally run longitudinally, are usually intergranular and it is obvious on inspection that the fracture occurred without deformation (brittle fracture).

The temperature range at which the cracks are initiated is difficult to determine and most investigators do not agree completely on this point.[1, 2, 3] Blue brittleness has up till recently been regarded as of no significance for welding.[2] This is understandable as this phenomenon is described as "brittleness occurring in steel when worked in the temperature range of 300–700° F. (= 150–370° C.) or when cold worked after being worked in this temperature range."

Recent publications about the elastic behavior of metals,[4] have resulted in a better understanding of the behavior of C and N in the ferrite crystal lattice. The phenomenon of blue brittleness has been explained and a quite different temperature range is considered from the one mentioned above. This is important from a welding point of view.

Therefore, it might be worth while to consider the observations and explanations mentioned in these publications and to establish their meaning in relation to weldcracking.

Blue brittleness is in fact an aging phenomenon. It occurs at higher temperature levels during plastic deformation.

It can be explained in exactly the same way as the phenomenon of strain aging and is attributed to the same causes.[4] The phenomenon of strain aging is characterized by an increase of the tensile strength and a decreased ability to elongation and reduction of area and in particular by discontinuous yielding.

It has been established that both the yield phenomenon and strain aging are due to C and N which remain or go into solution in the ferrite.[4]

They cannot reasonably be attributed to the presence of Fe_3C or the precipitation of nitride from supersaturated ferrite.

A number of observations have been reported to support this statement[4] such as:

1st: If mild steel is carefully decarburized and denitrided by a high temperature treatment with moist hydrogen the yield phenomenon is absent[6, 7, 8] and the steel is not liable to strain aging.[7, 8] Both phenomena return on recarbonizing and renitriding.[7, 8]

2nd: The O content is hardly influenced by the treatment with moist hydrogen.

O as well as H therefore are not causes of the yield phenomenon[7] or strain aging.

3rd: Blue brittleness has been found to occur even up to the ferrite austenite transition temperature.[5] It is only the strain rate that determines the temperature of its possible occurrence.

4th: The maximum effect of blue brittleness can be obtained at temperatures as high as 600°C. (1100° F.) by increasing the strain rate.[5]

This maximum decreases rather slightly with the temperature.

The following explanation for these phenomena has been given.[4]

In and around the slip planes the regular lattice structure is disturbed and in these imperfect zones, which are thermodynamically less stable, the solubility for C and N is increased.

On storage at room temperature or at higher temperatures the C and N concentration in the imperfect zones is increased by diffusion, consequently the resistance against plastic deformation increases as well.

The internal stresses in the crystal fragments, which were only elastically deformed, disappear or at least diminish. The C and N atoms thus return more or less to the equilibrium, re-establishing the yield phenomenon.

Considering the observations mentioned and the explanation of these phenomena, it appears to be of importance to establish whether hot cracks, in a weld, start under or over the ferrite austenite transition temperature. In austenite the C and N atoms are in equilibrium in a rather favorable position with regard to slip.[4] Therefore only cracks initiated under this temperature can possibly be related to blue brittleness.

Some authors believe that hot cracks are initiated well above 800° C. (1472° F.),[1] others[3] mention temperatures of 600° C. (1112° F.) and 200–300° C. (392–572° F.). Also 540° C. (1000° F.) "and above" are mentioned.[2]

If strain rates in the deposited weld metal at elevated temperatures under Ar_3 can be considered high enough, blue brittleness for which C and N are responsible might be a potential cause for hot cracks that cannot reasonably be attributed to other well-known harmful elements or circumstances.

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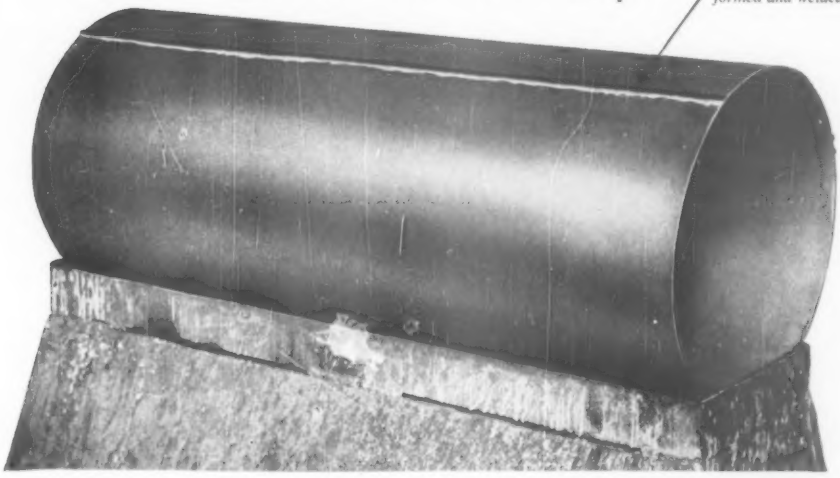

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